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## Calibrations to estimate absolute numbers of New Zealand fur seal (*Arctocephalus forsteri*) pups from direct counts

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### INTRODUCTION

New Zealand fur seals (*Arctocephalus forsteri* (Lesson 1828)) are increasing in number and expanding their range throughout their distribution in the New Zealand region (Lalas & Bradshaw 2001; Boren et al. 2006) and southern Australia (Gales et al. 2000; Shaughnessy & McKeown 2002; Goldsworthy et al. 2003; Shaughnessy et al. 2005) following the cessation of unsustainable hunting in the 19th century. The latest estimate provided for the size of the population in the New Zealand region is about 100 000 individuals, a deterministic total that lacks calculable confidence limits (Harcourt 2005).

Absolute abundance cannot be estimated from counts of all seals ashore because there are an unknown number at sea that are difficult to estimate without detailed records of shore attendance patterns (Eberhardt et al. 1979; Shaughnessy et al. 1994). Counts of pups offer the only definitive indicator of population size because young pups represent the only age class that is temporarily restricted to land (e.g., Chapman & Johnson 1968; Taylor 1982; Berkson & DeMaster 1985; Shaughnessy et al. 1994, 1995; Lalas & Harcourt 1995; Taylor et al. 1995). Population estimates are then extrapolated from numbers of pups by the application of a multiplier derived from the ratio of pups to older seals, deduced from population models (Lalas & Bradshaw 2001).

Pup population size estimates are derived from direct counts or from mark-recapture estimates. Direct counts are made while walking through sites occupied by pups (e.g., Lalas & Harcourt 1995; Lalas & Murphy 1998), from vantage points on land or at sea (e.g., Carey 1998), or from aerial surveys (e.g., Taylor 1982). Direct counts provide relative population size indices that can indicate long-term trends if executed consistently (Berkson & DeMaster 1985), but they do not estimate the total

**Abstract** Annual direct counts of seal pups can indicate long-term trends in population size, but mark-recapture estimates are needed to deduce absolute numbers. A calibration between results from these two methods would facilitate the use of direct counts to estimate absolute numbers, an outcome that is relatively quick, cheap and minimises disturbance of animals. Mark-recapture estimates for the numbers of New Zealand fur seal (*Arctocephalus forsteri*) pups in 2003 at 10 colonies at Otago, southeastern New Zealand, were compared with independent single counts at the same colonies. A single ratio to estimate absolute numbers ( $y$ ) from direct counts ( $x$ ) was not statistically significant. Instead, two ratios were deduced, based on differences in habitat among colonies:  $y = 1.51x$  for colonies with hiding places for pups and  $y = 0.96x$  for colonies without hiding places. Application of these calibrations and their 95% prediction intervals produce estimates and ranges for the absolute numbers of pups from single annual counts.

pup population because some pups may die before the count and others are missed when they hide out of sight under rocks (Shaughnessy et al. 1994; Gales et al. 2000; Lalas & Bradshaw 2001; Goldsworthy et al. 2007). Mark-recapture methods provide estimates of the absolute number of pups, but they involve handling of pups and repetitive counts within a season and are more time-consuming and expensive than direct counts (Shaughnessy et al. 1994; Gales et al. 2000).

Breeding colonies of New Zealand fur seals in New Zealand are delineated as discrete aggregations of pups along rocky coastlines in a variety of habitats quantified by Ryan et al. (1997) and Bradshaw et al. (1999). In this study, pup numbers derived from direct counts were compared with those derived from mark-recapture estimates for 10 colonies at Otago, southeastern South Island, New Zealand. The aim was to investigate the efficacy of a single annual direct count as an index of the absolute number of pups at a colony. An ideal index should be monotonic (Caughley & Sinclair 1994); bias is acceptable provided it is known and quantified (Williams et al. 2002). A reliable calibration of direct counts to absolute numbers would mitigate the disturbance of pups, and be quicker and cheaper than mark-recapture estimates.

The concept followed was similar to that developed to estimate numbers of pups at colonies missed during annual counts from aerial photographic surveys of Cape fur seals (*A. pusillus pusillus*)—rather than a single calibration index to estimate pup numbers at missed colonies, spatial and temporal differences in annual pup production necessitated the generation of a series of location-specific and year-specific indices (Kirkman et al. 2007).

## MATERIALS AND METHODS

Mark-recapture experiments of pups at 10 New Zealand fur seal breeding colonies at Otago, South Island, New Zealand, were conducted from mid February, 2–3 weeks after the end of birthing (Lalas & Harcourt 1995), to the end of May 2003 (Table 1) when pups were up to 6 months old. Six of the colonies were spread along 15 km of Otago Peninsula separated by 0.3–4.7 km (average separation 2.3 km  $\pm$  1.9 SD); three of the colonies were 0.3–0.7 km apart at Nugget Point, 80 km southwest of Otago Peninsula; and one colony was at Tucks Cove, 3 km southwest of Nugget Point. Colonies are described in Lalas & Murphy (1998), Bradshaw

et al. (2000), and Watson (2004). Compared with earlier descriptions, the three colonies studied at Nugget Point expanded spatially since depictions in Lalas & Murphy (1998), the Tucks Cove colony was new, initiated in 2000/01 (C. Lalas pers. obs.), and the areas of Otago Peninsula colonies remained unchanged and matched descriptions by Bradshaw et al. (2000).

Descriptions of the terrestrial habitat of colonies followed terminology in Ryan et al. (1997) and Bradshaw et al. (1999). Some colonies encompassed more than one terrain type and some included vegetation. The 10 colonies studied in 2003 encompassed a variety of terrains and two included substantial coverage of scrub vegetation (>20% by area) (Table 1). The visibility of pups during counts was reduced with the occurrence of hiding places created by terrain or scrub (dense vegetation typically to 2 m high; at Otago, predominantly kokomuka *Hebe elliptica* and flax *Phormium tenax*). Colonies were assessed qualitatively and categorised by the presence or absence of hiding places for pups. Two types of terrain could provide hiding places: rounded boulders (typically >2 m diam.) and talus (tumbledown angular rocks).

Pups were caught by hand (Lalas & Harcourt 1995) or with a noose pole (Gentry & Holt 1982). Attempts were made to catch all pups encountered in colonies; marked pups were released near site of capture to facilitate mixing with unmarked pups after release (Bradshaw et al. 1999). Pups were marked by having a small patch (2–3 cm<sup>2</sup>) of fur clipped from the top of the head to expose the pale underfur (Shaughnessy et al. 1995).

To estimate the population of pups at each colony using mark-recapture, we returned to each colony within one week after marking and counted the number of marked and unmarked pups while walking from one end of the colony to the other, paying particular attention to potential hiding places (Shaughnessy et al. 1995; Bradshaw et al. 1999, 2000). Pups which had the area of marking hidden from view were excluded from the mark-recapture estimate. These counts were repeated 6–9 times over 1–4 days at each colony by up to four people. The size of the population of pups at each colony after each count ( $N_i$ ) was estimated with the Chapman version of the Lincoln-Petersen estimator (White 1996):

$$N_i = \frac{(n_i + 1)(n_{i+1} + 1)}{m_{i+1} + 1} - 1$$

where  $n_1$  = number of pups marked in the first sample,  $n_{1+i}$  = number of pups counted in session  $1+i$  (e.g., the first count following marking = session 2), and  $m_{1+i}$  = number of marked pups counted in the  $(1+i)$ th session. The estimate from the combination of all recapture sessions was generated using the program NOREMARK (White 1996) that applies the joint hypergeometric maximum likelihood estimation method of Bartmann et al. (1987) to produce a mean and 95% CI.

The estimate for the population of pups at each colony derived from the mark-recapture model was compared with an independent annual count done once at each colony from 18 January to 14 February 2003, following Lalas & Harcourt (1995) and Lalas & Murphy (1998). These annual counts were done only on fine days with calm seas, conditions considered prerequisites for safely accessing the foreshore and clambering over rocks.

The annual direct count of pups was designated as the independent variable ( $x$ ) and the mean mark-recapture estimate as the dependent variable ( $y$ ), following the assumption that these two parameters were related. The ratio  $y/x$  was designated as the calibration index for each colony. Relationships  $y$  and  $x$  among colonies were investigated with least-squares regressions, with precision set to three significant values. Fitting of regressions followed Zar (1999) and included calculations for 95% CI (the likely spread of the line of best fit) and 95% prediction intervals (PI, the likely scatter of data) for regression lines. Five regression analyses were applied to generate lines of best fit—three for lines not fixed through the origin (simple linear, log-linear, and linear-log), and two for lines fixed through the origin (simple linear and power).

Inappropriate application of linear regressions through the origin produces spurious relationships (Bissell 1992; Eisenhauer 2003). Most relevant to the relationship investigated here was the implication of error assumptions. If stochasticity is designated as proportional to  $x$ , then CI varies with  $x$  and CI = 0 when  $x = 0$ ; and if stochasticity is designated as homogeneous, then CI is approximately parallel to the regression line and creates the anomaly that CI  $\neq 0$  when  $x = 0$  (Bissell 1992). Here stochasticity for linear regressions through the origin was assumed to be homogeneous, with CI and PI calculated following Zar (1999). This option accounted for the possibility that the linear regression did not pass through the origin. The difference between two regression coefficients was investigated with a  $t$  test following Zar (1999).

## RESULTS

Calibration indices for the 10 New Zealand fur seal colonies at Otago in the 2002/03 breeding season varied from 0.93 to 1.94 (Table 1). The lowest calibration indices (0.93–1.00) were from the only three colonies that had no hiding places for pups: two on bare bedrock (Table 1, colonies C and D) and one on bare bedrock and rounded boulders (Table 1, colony I). The highest calibration indices (1.68–1.94) were from the two colonies where talus predominated: one in bare talus (Table 1, colony J) and one in talus and scrub vegetation (Table 1, colony A). Calibration indices from the other five colonies (1.26–1.55) were between the two extremes and were from colonies with mixed terrain: one on bare bedrock abutted by scrub vegetation (Table 1, colony G), one on a mix of bedrock and talus (Table 1, colony B), and three on a mix of bare rounded boulders and talus (Table 1, colonies E, F, and H).

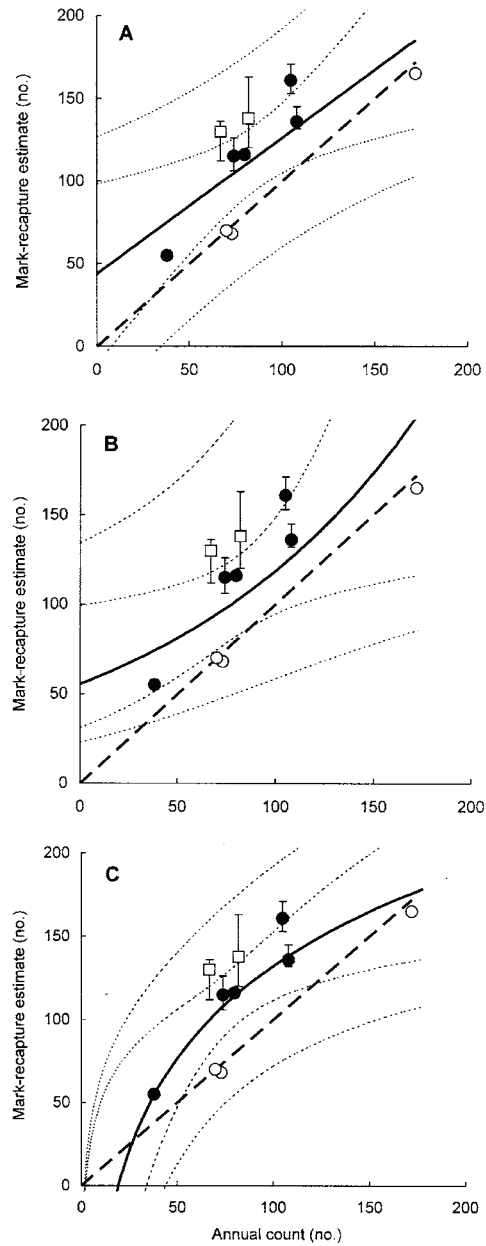
Regressions between mark-recapture estimates ( $y$ ) and annual direct counts ( $x$ ) of live pups at the 10 colonies generated statistically significant relationships for the three analyses for lines not fixed through the origin: simple linear regression ( $y = 0.821x + 44.0$ ,  $r^2 = 0.569$ ,  $P < 0.05$ ), log-linear regression ( $y = 55.6(10^{0.003x})$ ,  $r^2 = 0.505$ ,  $P < 0.05$ ), and linear-log regression ( $y = 185\log_{10}x - 238$ ,  $r^2 = 0.645$ ,  $P < 0.01$ ) (Fig. 1). These three regressions produced implausible outcomes when extrapolated below the data range: from the linear regression  $y = 44$  for  $x = 0$ , for the log-linear regression  $y = 56$  for  $x = 0$ , and for the linear-log regression  $y < 0$  for  $x < 20$ . Implausible outcomes were precluded by the two analyses for lines fixed through the origin: simple linear regression ( $y = 1.26x$ ,  $r^2 = 0.381$ ,  $P > 0.05$ ), and power regression ( $y = 3.45x^{0.785}$ ,  $r^2 = 0.622$ ,  $P < 0.01$ ) (Fig. 2). Here the correlation coefficient for the linear regression through the origin was not statistically significant.

Data for the 10 colonies were subsequently separated into two groups: the presence or absence of hiding places for pups. Correlation coefficients for linear regressions through the origin were statistically significant for both groups: seven colonies with hiding places for pups ( $y = 1.51x$ ,  $r^2 = 0.726$ ,  $P < 0.05$ ), and three colonies without hiding places for pups ( $y = 0.96x$ ,  $r^2 = 0.999$ ,  $P < 0.05$ ) (Fig. 3). The difference between the two regression coefficients (1.51 and 0.96) was statistically significant ( $v = 6$ ,  $t = 3.67$ ,  $P < 0.05$ , where  $2.45 < t < 3.71$  for  $0.05 > P > 0.01$ ).

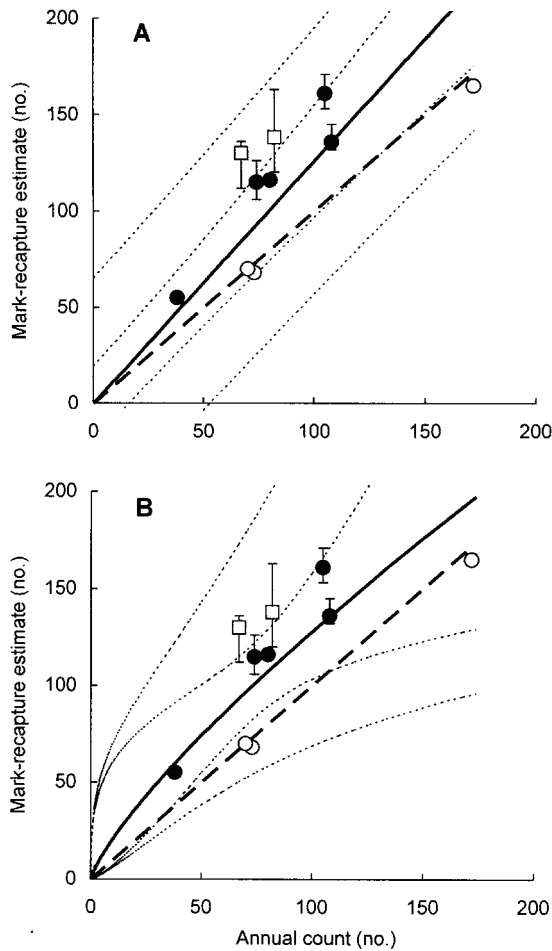
The significant difference between regression coefficients justified the application of two habitat-specific calibration indices to estimate the actual

**Table 1** Location and habitat, and annual direct count, mark-recapture estimate, 95% CI, and calibration index ( $y/x$ ) for live pups at the 10 New Zealand fur seal (*Arctocephalus forsteri*) colonies studied at Otago in the 2002/03 breeding season.

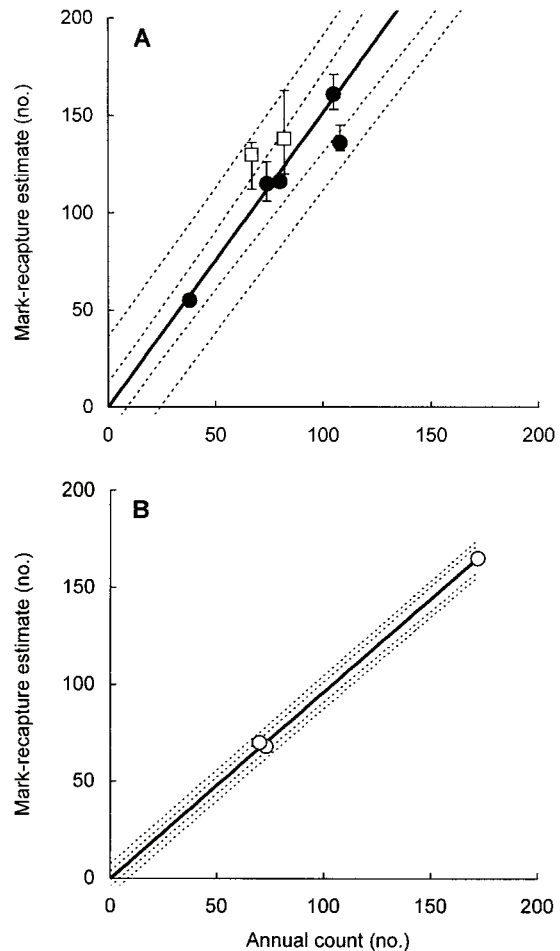
Colony name (north to south)	Latitude (South)	Longitude (East)	Habitat(s) used by most pups	Hiding places for pups	Annual count $x$	Mark-recapture estimate			$y/x$
						Estimate (y)	CI	No. counts	
A Victory Beach	45°49'	170°44'	Talus and scrub	present	82	138	120–163	6	1.68
B Fuchsia Gully	45°51'	170°45'	Bare bedrock and talus	present	105	161	153–171	7	1.53
C Puddingstone North	45°52'	170°45'	Bare bedrock	absent	172	165	163–168	9	0.96
D Puddingstone South	45°53'	170°45'	Bare bedrock	absent	73	68	67–70	7	0.93
E Cape Saunders	45°53'	170°44'	Bare rounded boulders and talus	present	108	136	132–145	8	1.26
F Sandymount North	45°53'	170°41'	Bare rounded boulders and talus	present	74	115	106–126	6	1.55
G Nugget Point M3	46°26'	170°48'	Bare bedrock and abutting scrub	present	80	116	114–119	9	1.45
H Nugget Point M1	46°27'	169°48'	Bare rounded boulders and talus	present	38	55	53–58	6	1.45
I Nugget Point S5	46°27'	169°49'	Bare bedrock and rounded boulders	absent	70	70	70–72	7	1.00
J Tucks Cove	46°28'	169°46'	Bare talus	present	67	130	125–136	8	1.94



**Fig. 1** Three regressions not fixed through the origin for relationships between mark-recapture estimates for pups ( $\pm$ CI) and the annual direct counts for the 10 New Zealand fur seal (*Arctocephalus forsteri*) colonies investigated. **A**, Simple linear regression; **B**, log-linear regression; **C**, linear-log regression. Symbols differentiate colonies into three without hiding places for pups (open circles), two mainly in talus (open squares), and five in mixed terrain (closed circles). Regression line (solid) is flanked by CI (inner pair dotted lines) and PI (outer pair dotted lines). Dashed line delineates  $y = x$ .



**Fig. 2** Two regressions fixed through the origin for relationships between mark-recapture estimates for pups ( $\pm$ CI) and the annual direct counts for the 10 New Zealand fur seal (*Arctocephalus forsteri*) colonies investigated. **A**, Simple linear regression; **B**, power regression. Symbols differentiate colonies into three without hiding places for pups (open circles), two mainly in talus (open squares), and five in mixed terrain (closed circles). Regression line (solid) is flanked by CI (inner pair dotted lines) and PI (outer pair dotted lines). Dashed line delineates  $y = x$ .



**Fig. 3** Linear regressions fixed through the origin for relationships between mark-recapture estimates for pups ( $\pm$ CI) and the annual direct counts for **A**, seven New Zealand fur seal (*Arctocephalus forsteri*) colonies with hiding places for pups, and **B**, three colonies without hiding places. Symbols differentiate colonies into three without hiding places for pups (open circles), two mainly in talus (open squares), and five in mixed terrain (closed circles). Regression line (solid) is flanked by CI (inner pair dotted lines) and PI (outer pair dotted lines).

number of pups ( $y$ ) in a colony from a single annual direct count ( $x$ ), with error range represented by PI. For colonies with hiding places,  $y = 1.51x$ , with the approximation for PI from  $1.47x - 34.9$  to  $1.56x + 34.9$ ; here PI as a proportion of the estimate through the recorded data range varied from  $\pm 0.25y$  (for  $x$

$= 108$ ) to  $\pm 0.64y$  (for  $x = 38$ ). For colonies without hiding places,  $y = 0.96x$ , with the approximation for PI from  $0.95x - 7.0$  to  $0.98x + 7.0$ ; here PI as a proportion of the estimate through the recorded data range varied from  $\pm 0.06y$  (for  $x = 108$ ) to  $\pm 0.12y$  (for  $x = 70$ ).

## DISCUSSION

Mark-recapture experiments have provided accurate estimates for numbers of pups at some New Zealand fur seal colonies in New Zealand (Mattlin 1978; Bradshaw et al. 1999, 2000; Boren et al. 2006), but they have not been sufficiently comprehensive to produce accurate regional estimates. Instead, regional estimates have been calculated either as the sum of single direct counts of pups at all colonies (e.g., Wilson 1981; Taylor 1982; Carey 1998; Lalas & Murphy 1998), or from a calibration index deduced from the mark-recapture estimate at one colony applied to other colonies (Lalas & Harcourt 1995; Taylor et al. 1995). The two habitat-specific calibration indices derived in this study cannot be regarded as replacements for mark-recapture estimates. However, these indices and their associated error ranges applied to direct counts provide estimates of absolute numbers of pups that are more accurate than the untransformed direct counts.

The problem of accounting for pre-census mortality of pups remains unresolved. Mark-recapture experiments assume population closure to birth, death and immigration/emigration (Seber 1982), and so the number of pups that die between birth and survey must be assessed independently and then added to mark-recapture estimates of live pups to produce an estimate for pup production. Direct counts of dead New Zealand fur seal pups during surveys have been used to estimate this mortality at 1–2% in Australia (e.g., Gales et al. 2000; Shaughnessy et al. 2005) and 5% in New Zealand (Bradshaw et al. 2003), although the true number of pup deaths remains unknown because some carcasses are washed away or decompose before the survey begins (Gales et al. 2000). These assessments were restricted to the survey period and probably underestimated pre-census mortality—Mattlin (1978) and Lalas & Harcourt (1995) estimated that pup mortality was about 20% from first birth to age 50 days, a duration that coincided with surveys in February.

Caution is required if the calibration indices are applied to direct counts of pups less than the minima recorded in this study (<38 for colonies with hiding places for pups and <70 for colonies without hiding places)—the upper limit of the error range becomes implausibly large and the lower limit becomes negative. Lalas & Harcourt (1995) assigned direct counts as equal to absolute numbers for colonies with direct counts <50 pups. With the benefit of hindsight, this approach is unjustified and a calibration index should be applied to all colonies because there was nothing to indicate that the visibility of pups was affected by colony size.

The efficacy of the application of calibration indices to direct counts could be improved and customised during future mark-recapture experiments in two ways. Sample size and range could be increased by calculation of the ratio between absolute numbers of pups and direct counts; and description of the habitat within colonies may serve to further diversify habitat-specific calibration indices.

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