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MODELLING VARIABILITY AND ESTIMATING POWER TO DETECT CHANGE IN ADÉLIE PENGUIN FLEDGLING WEIGHTS

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Abstract

Statistical models of variation in Adélie penguin fledgling weight data were used to examine the power to detect a change in fledgling weights after an impact. The statistical models were developed from first principles and incorporated both within- and between-year variability of fledgling weights. These models assume that data are collected during a fixed CEMP five-day period corresponding to the average peak fledging period. Modelling assumes that fledgling weights are likely to respond to resource availability as a step change represented as either a percentage increase or decrease after an impact. Fledgling weight was found to decline through the fledging period each year, but there was no evidence that the rate of decline differed between years. A consequence of this finding is that it may be possible to simplify future monitoring, such that fledgling weight is measured at a single time each year, without substantial loss of power to detect change. Further modelling work is identified to investigate this possibility. Modelling also indicated the potential for reducing the number of birds weighed in each five-day period from 50 to 30 without substantial loss of power. If practical, these findings could have substantial benefits by simplifying data collection.

Résumé

Des modèles statistiques de variation des données de poids de jeunes manchots Adélie en mue ont servi à examiner la puissance de détection d'une variation du poids des jeunes après un impact. Les modèles ont été construits sur la base des premiers principes et ils incorporent la variabilité inter et intra-annuelle du poids des jeunes en mue. Ces modèles présument que les données sont collectées pendant une période fixe du CEMP, de cinq jours, correspondant à la période de pointe moyenne de la première mue et que le poids des jeunes en mue est susceptible de répondre à la disponibilité des ressources en tant que changement en forme de marche représenté par une hausse ou une baisse du pourcentage après un impact. Le poids des jeunes en mue semblerait baisser chaque année à la période de la mue, mais rien ne semble indiquer que le taux de cette baisse diffère d'une année à une autre. En conséquence, il serait peut-être possible de simplifier les suivis, afin de ne devoir relever le poids des jeunes en mue qu'une fois par an, sans que cela n'affecte grandement la puissance de détection. D'autres travaux de modélisation sont identifiés pour étudier cette possibilité. La modélisation met également en évidence la possibilité de réduire à 30 au lieu de 50 le nombre d'oiseaux pesés par période de cinq jours sans grande incidence sur la puissance de détection. Si cela était réalisable, ces conclusions pourraient s'avérer des plus utiles en permettant de simplifier la collecte des données.

Резюме

Статистические модели изменчивости в данных о весе оперившихся птенцов пингвинов Адели использовались для изучения эффективности обнаружения изменений в весе оперившихся птенцов после воздействия. Статистические модели были разработаны исходя из основных принципов и включили как внутри-, так и межгодовую изменчивость веса оперившихся птенцов. Эти модели предполагают, что данные собирались в течение установленного 5-дневного периода CEMP, соответствующего среднему пиковому периоду оперения. Моделирование исходит из того, что вес оперившихся птенцов, по-видимому, реагирует на наличие ресурсов как ступенчатое изменение, представленное в виде процентного увеличения или сокращения после воздействия. Выявлено, что вес оперившихся птенцов на протяжении периода оперения уменьшается каждый год, однако нет свидетельств того, что темпы сокращения различаются между годами. Полученные результаты, возможно, помогут упростить проведение мониторинга в будущем, так чтобы измерять вес оперившихся птенцов каждый год в одно время без существенного снижения эффективности обнаружения изменений. Для изучения этой возможности намечены дополнительные работы по моделированию. Моделирование также свидетельствует о возможности сократить количество птиц, взвешиваемых за 5-дневный период, с 50 до 30 без существенного снижения эффективности. При применении на практике эти результаты могут оказаться полезными тем, что приведут к упрощению сбора данных.

Resumen

Se utilizaron modelos de variación estadística de los datos del peso de los pingüinos adelia al emplumecer a fin de estudiar la capacidad para detectar cambios en este parámetro después de un impacto. Los modelos estadísticos fueron desarrollados a partir de primeros principios e incorporaron la variabilidad tanto anual como interanual del peso de los polluelos al emplumecer. Estos modelos presuponen que los datos se recopilan durante un período fijo de cinco días del CEMP, que corresponde a la fecha promedio cuando emplumece un máximo número de polluelos. La simulación supone que el peso al emplumecer reflejará la disponibilidad de recursos como un cambio escalonado, en la forma de un porcentaje de aumento o de disminución después de un impacto. Se encontró que cada año el peso de los polluelos disminuye a medida que emplumecen, aunque no hubo indicios de variabilidad interanual en la tasa de disminución. Como resultado de esto se podría simplificar el seguimiento en el futuro, midiendo el peso al emplumecer una sola vez en el año, sin una reducción significativa de la potencia del modelo para detectar un cambio. Se ha descrito el trabajo adicional de simulación necesario para investigar esta posibilidad. La simulación también destacó la posibilidad de reducir de 50 a 30 el número de aves que se deben pesar cada cinco días, sin que se experimente una pérdida considerable de la potencia. De ser esto factible, se podrá simplificar considerablemente el proceso de recopilación de datos.

Keywords: Adélie penguin, fledgling weight, power analysis, interannual variability, Mawson, CEMP, CCAMLR

Introduction

Fledgling weight is one of several parameters originally recommended for measurement in the CCAMLR Ecosystem Monitoring Program (CEMP). At the time of development of the program, fledgling weight was thought to reflect prey availability as well as possibly indicating predator performance via an effect on first-year survival over the winter period at sea, with lighter chicks less likely to survive than heavier chicks (CCAMLR, 1997). Since this recommendation, there have been varying views in the literature on the utility and interpretation of fledgling weight as an index of prey availability. Although several papers question its usefulness (Williams and Croxall, 1990; Bost and Jouventin, 1991; Williams and Croxall, 1991), Croxall (1989) regards fledgling weight to have 'potentially high relevance and appropriate accuracy and detectability' for detecting short-term change.

The ability to detect a change in a parameter over time is dependent on the amount of natural variability (process variation) and noise inherent in measuring a parameter (sampling variation) (Thompson et al., 1998). In the case of penguin fledgling weights, several sources of variability exist: (i) measurement error, (ii) within-year variability, and (iii) between-year variability (Emmerson et al., 2003). Within- and between-year variability are the most prominent of these. Within-year variability reflects the natural decline of fledgling weights over a three- to four-week period from the time parental feeding either ceases or becomes less frequent until fledgling departure from the colony. In contrast, between-year variability is due to the natural variability of underlying resources as well as the demography of the breeding birds.

In this paper, the consequences of natural between- and within-year temporal variability on the power to detect change in fledgling weights are explored. Statistical models were developed from first principles and incorporate multiple sources of variability that influence fledgling weights. These models are used to examine the scenario of a sudden change in fledgling weight in response to a decline in resource availability.

Methods and results

Data used for modelling

Adélie penguin fledglings have been weighed annually at Béchervaise Island (67°35'S 62°49'E), near Mawson Station in East Antarctica, since the 1990/91 breeding season, as part of CEMP. During that time there has been no krill fishery operating

Table 1: Number of birds weighed in each CEMP five-day period according to year. Totals of birds per year and per five-day period, all years combined. Years indicated by * are included in the final analysis. Shaded cells indicate peak fledging period according to simultaneous chronological studies.

Year	CEMP 5-day period					Total
	1: 10–14 Feb	2: 15–19 Feb	3: 20–24 Feb	4: 25 Feb–1 Mar	5: 2–6 Mar	
1: 1990–1991			50			50
2: 1991–1992*			50	50	50	150
3: 1992–1993*				50	44	94
4: 1993–1994*		50	50	21		121
5: 1994–1995						
6: 1995–1996*	50		23		51	124
7: 1996–1997*		50	50	35		135
8: 1997–1998						
9: 1998–1999*			50	20	15	85
10: 1999–2000		50				50
11: 2000–2001*		50	50	50		150
12: 2001–2002*	50	50	50			150
Total	100	250	373	226	160	1109

in the region, so these data can be considered to provide pre-impact or baseline data prior to a possible future impact due to a krill fishery.

Analyses in this paper use data from 12 split-year breeding seasons (1990/91 to 2001/02) which commence in October of one year and finish in late March of the following calendar year (hereafter referred to as years). In each of the 12 years, an attempt was made to measure the weight of 50 fledglings during each of five five-day CEMP periods (dates of the five periods are given in Table 1) as recommended by the CEMP Standard Methods (CCAMLR, 1997). All dates for measuring fledgling weights were converted to the five-day period codes (Table 1) which were used in subsequent analyses as the date variable. Due to weather and logistical constraints, the recommended sample size was often not achieved (Table 1). No data were obtained for years 1994/95 and 1997/98, and in years 1990/91 and 1999/2000 data were obtained in only one five-day period. These years were excluded from the analysis because they provided no information about the rate of change in fledgling weights over the breeding season. Although data were collected in five-day period 1 (10–14 February) in two years, these data were excluded from modelling because their inclusion would have required extrapolation of data to period 1 in all other years. Consequently, the analysis was limited to eight years and to the five-day periods 2–5 starting on 15 February and ending on 6 March. Chronological studies over the same period indicated that the peak fledging date fell between five-day periods 2–4 but most frequently in period 3 (Table 1).

Monitoring scenario

Development of the models below is based on the following monitoring scenario: (i) fledgling weight data are collected for each of a number of consecutive years prior to an impact (pre-impact or 'baseline' data) and a number of years after that impact (post-impact data), (ii) the impact may cause a systematic change in fledgling weight from pre- to post-impact years, and (iii) the change is step-wise in form.

Modelling and estimating variation in fledgling weight during the pre-impact period

Model development

An initial model for variation in fledgling weight during the pre-impact period was proposed, based on the assumptions that: (i) no systematic trend occurred over years, (ii) year-to-year variation was random, (iii) a linear trend in weight with date of measurement within each year may exist, (iv) the relation between weight and date within year may vary from year to year, and (v) effects are linear and additive.

Under these assumptions, variation in fledgling weight can be described by the model equation:

$$y_{ij} = A + S_i + (B + s_i)x_{ij} + e_{ij} \quad \text{for } i = 1,2,\ldots,r;\ j = 1,2,\ldots,n_i. \qquad (1)$$

where y_{ij} is the fledging weight of penguin j in year i, A is the intercept, S_i is a random adjustment to mean weight for year i, B is the slope (average rate of change in weight per five-day period), s_i is a random adjustment in the slope for year i, x_{ij} is the coded date value for penguin j in year i, and e_{ij} is the unexplained component for fledgling j in year i. The number of penguins measured in year i is n_i and r is the number of pre-impact years. It was assumed that the S_i, s_i and e_{ij} terms are independent and are normally distributed with mean 0 and variance σ_S^2, σ_{st}^2 and σ^2 respectively. Model checking supported these assumptions.

Initial fitting of data to this model indicated there was no evidence that the rate of change in weight within a year differed between years, i.e. the hypothesis $\sigma_{st}^2 = 0$ is reasonable ($p = 0.189$). Consequently, equation (1) was simplified by omitting the s_i term. However, there is evidence of between-year variability, i.e. the hypothesis $\sigma_S^2 = 0$ is rejected ($p < 0.001$). Thus the model that was fitted is represented by the model equation

$$y_{ij} = A + S_i + Bx_{ij} + e_{ij} \quad \text{for } i = 1,2,\ldots,r;\ j = 1,2,\ldots,n_i. \qquad (2)$$

The long-term estimator of average fledgling weight at the mid-point of any five-day period x is $\hat{M}_x = \hat{A} + \hat{B}x$, where $\hat{A}$ and $\hat{B}$ are estimators of A and B in equation (2). It is noted that the variance of $\hat{M}_x$ is a function of two variance components, the between-year variance (σ_S^2), and the between-fledgling-within-year variance (σ^2). The estimated average weights for individual years may be determined for year i from $\hat{M}_x = \hat{A} + \hat{S}_i + \hat{B}x$, where $\hat{S}_i$ is the estimated difference in average weight of fledglings in year i compared to the long-term average.

Model parameters and variance estimates

Analysis of variance results from the fitting of data over eight years for five-day periods 2–5 indicated a significant relation between mean fledgling weight and date of weighing ($p < 0.001$).

Estimates of the parameters A and B in equation (2) were employed in equation (3) to estimate mean weight as a function of five-day period x:

$$\hat{M}_x = 3\,649.5 - 151.046 \times x. \qquad (3)$$

Using this equation, estimated mean weights for the periods 2–5 are: period 2: 3 347 g; period 3: 3 196 g; period 4: 3 045 g; and period 5: 2 894 g.

Figure 1 displays the observed mean fledgling weight for each year/date combination, with the estimated long-term trend line superimposed. The variation in mean fledgling weight from year to year is evident, with the 1996/97 and 1998/99 years recording lower average weights than other years. Estimates of between-year (σ_S^2) and between-fledgling-within-year (σ^2) variance components are 15 008 and 296 376 respectively. Because of the unbalanced data structure, the formulae employed in the variance component analysis are not representable analytically.

Modelling and estimating variation in fledgling weight during a post-impact period

Model development

The pre-impact statistical model was extended to include the effects of a non-natural impact on fledgling weights, and power analyses were performed using this extended model to determine the power to detect change in fledgling weight due to a non-natural impact. Because there was no evidence, from pre-impact data, of between-year variation in the within-year rate of decline in fledgling weight, the post-impact modelling scenario was based on a monitoring strategy of collecting data during only one CEMP five-day period in each post-impact year rather than continually throughout the entire fledging period. This simplified monitoring strategy takes advantage of the finding of a constant within-year rate of decline in fledgling weight, but does not involve or allow determination of the time of peak fledging. A lack of data on the time of peak fledging would not compromise or invalidate the power predictions developed below, as variation in the time of peak fledging between years is incorporated in estimates of the total between-year pre-impact variation. However, this strategy may lead to the power to detect change being lower than a more intensive monitoring strategy where data are collected continually throughout a year and the date of peak fledging is determined. Accounting for variation in the time of peak fledging to improve power would require further extension of the post-impact model and is not explored here.

Development of the following statistical model is based on a scenario in which it is assumed that data are collected on fledgling weights on date x for samples of n fledglings per year (1) in each of r years prior to an impact, and (2) for c years after the impact, in circumstances where the impact results in a change in mean long-term fledgling weight by an amount δ.

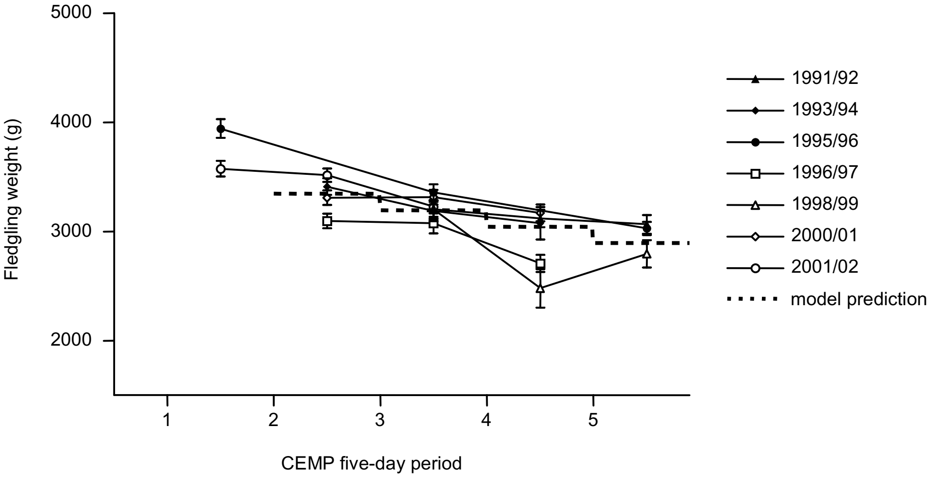

Figure 1: Mean and standard deviation of fledgling weights measured for each CEMP five-day period for each year. The dashed line indicates model predictions of expected weight in each five-day period.

Based on the same statistical model as is employed above, the linear, additive model equations are

$$\begin{aligned} y_{ij} &= M_x + S_i + e_{ij} \\ &\quad \text{for } i = 1,2,\ldots,r; \\ &\quad j = 1,2,\ldots,n \qquad \text{(pre-impact)} \\ &= M_x + \delta + S_i + e_{ij} \\ &\quad \text{for } i = r+1,\, r+2,\ldots,r+c; \\ &\quad j = 1,2,\ldots,n \qquad \text{(post-impact).} \end{aligned} \tag{4}$$

Distributional assumptions are those associated with equation (1).

Under this scenario, the mean fledgling weight for the pre-impact and post-impact periods, $\bar{y}_{pre}$ and $\bar{y}_{post}$, are normally-distributed statistics with means M_x and $M_x + \delta$ respectively. Assuming the impact has resulted in a possible long-term change in mean fledgling weight at time x without a change in variability, then the variances of the two sample means are $\sigma^2_{\bar{y}_{pre}} = \frac{\sigma^2_s}{r} + \frac{\sigma^2}{rn}$ and $\sigma^2_{\bar{y}_{post}} = \frac{\sigma^2_s}{c} + \frac{\sigma^2}{cn}$ respectively. If it were anticipated that variability was also affected by the impact, then the between-year variance component σ^2_S and between-fledgling-within-year variance component σ^2 would generally take different values before and after impact.

Variance estimation

Estimates of σ^2_S and σ^2 can be computed, based on data collected from each of n fledglings in each of r years preceding an impact. Additionally, estimates of variance can be computed from the post-impact data (provided c is greater than 1). The pre- and post-impact estimates can be combined and the values obtained inserted into the above formulae for variance of means to give estimated variances for the pre-impact and post-impact means that are denoted by $s^2_{\bar{y}_{pre}}$ and $s^2_{\bar{y}_{post}}$ respectively.

Power to detect change between pre- and post-impact data

Model development

Given the above statistical models and parameter estimates for pre- and post-impact data, it is possible to determine the power to detect change between pre- and post-impact periods, in respect of the null hypothesis of no change after impact, i.e. H_0: $\delta = 0$.

The statistic $t = \frac{\bar{y}_{post} - \bar{y}_{pre}}{s_{\bar{d}}}$ where $s_{\bar{d}} = \sqrt{s^2_{\bar{y}_{pre}} + s^2_{\bar{y}_{post}}}$ is suggested as providing the most powerful test of the null hypothesis. It is assumed that, under the null hypothesis, the distribution of the statistic t is well approximated by a t-distribution with $d = (r - 1) + (c - 1)$ degrees of freedom.

If interest lies in the detection of a change in the expected mean weight of δ with regard to a specific direction of change, e.g. $H_0 : \delta = 0$ versus $H_1 : \delta > 0$, then the power of the test can be determined using a non-central t-distribution, as $\Pr(t(d,\lambda) > t_\alpha(d))$ where $t(d,\lambda)$ has a non-central t-distribution with d degrees of freedom and non-centrality parameter $\lambda = \delta / s_{\bar{d}}$ and $t_\alpha(d)$ is the upper α% quantile from a t-distribution with degrees of freedom d. If the alternative hypothesis does not specify the likely direction of change, i.e. a two-sided test is employed,

$$\Pr(t(d,\lambda) > t_{\alpha/2}(d)) + \Pr(t(d,\lambda) < -t_{\alpha/2}(d)).$$

Using the statistical models outlined above, the power to detect a change in fledgling weight between pre-and post-impact periods was investigated for a range of post-impact monitoring scenarios including numbers of fledglings weighed each year (30, 50 and 100), duration of post-impact monitoring (3, 4 and 5 years), and percentage change in weight required to be detected (0, 2, 4,…., and 20%). In all cases, power is assessed for detecting directional percentage change from an overall mean weight of 3 139 g.

Power estimates

Power for the scenarios investigated is shown in Figures 2 and 3. The key points to be noted are the potential for identifying a 12% change (377 g) with only three years of post-impact monitoring and the limited gain from weighing more than 30 birds each year. This is the case for both one- and two-tailed tests with a power greater than 0.8. There was very little gain in power to detect change by increasing the number of birds measured from 50 to 100 per year. After five years of post-impact monitoring, the minimum detectable level of change with power 0.8 is 8% (251 g) with measurements of 100 birds for one-tailed tests.

In the case in which the direction of change is unknown and a two-tailed test is used (Figure 3), the percentage change detectable with power 0.8 or greater is reduced. For example, after five years of monitoring 50 birds each year, the smallest level of detectable change is 10% (an increase or decrease of 314 g). In contrast, after three years of monitoring, the minimum level of change is 12%, reflecting an increase or decrease in average weight of 377 g.

Discussion

When the standard method for measuring Adélie penguin fledgling weight for CEMP was established, the recommendation was for measurements to be made throughout the fledging period in each year to account for possible within-year variation (CCAMLR, 1997). This analysis confirms that such within-year variation exists, which to some extent validates the early recommendation for within-year measurement. However, the lack of evidence for between-year variation in the within-year decline suggests that it may be possible, despite the existence of within-year variation, to simplify future monitoring strategies by measuring fledgling weight at just one time in each year. This would have substantial operational advantages for field programs, and is the basis of the post-impact model and power predictions developed here. Such operational advantages, however, would need to be weighed against the possible disadvantage of reduced power due to a lack of data on time of peak fledging.

As the time of peak fledging was found to vary from year to year, it may make some contribution to the total between-year variation in fledgling weight, and this contribution may be independent of variation due to 'external' factors such as food availability. If data on time of peak fledging are available, as would be the case if measurements are made throughout the fledging period, it would be possible to account for this source of variation in the modelling and variance estimation process, and so maximise power to detect change related to other factors. This would not be possible, however, if the monitoring strategy were simplified to measurement at a single time each year. The magnitude of the loss in power associated with simplifying the monitoring strategy will depend on the size of the contribution due to variation in the time of peak fledging to total between-year variation. This could be assessed by extending the model developed here to include time of peak fledging as a covariate, which could be a subject of future work.

A further finding with operational consequences is that the currently recommended sample size of 50 birds in each five-day period could be reduced to 30 without any substantial loss of power to detect change. Analysis of other long-term datasets that have resulted from the application of CEMP over the past one to two decades, would allow an assessment of whether this finding can be applied more generally to other sites and species.

The statistical models developed in this paper consider a step change in fledgling weight after an impact occurs. Thus, following an impact that results in a decline in resource availability, the expected response is either a decrease or an increase in fledgling weights. Sudden sharp impacts ('pulse' changes) can induce equally sudden, sharp changes in population parameters such as those reported in Bunce et al. (2005) for gannets on the Australian coast. Alternatively, trends may occur if the impact is of a gradual and sustained nature (a 'press' change (Underwood, 1993)). In this regard, other forms of change in fledgling weights in response to an impact are possible, and could be explored using other models. It is currently not clear whether the impact of fishing would result in step or trend changes.

Another uncertainty in the detection of change in the fledgling weight parameter is the direction of change that might be expected in response to

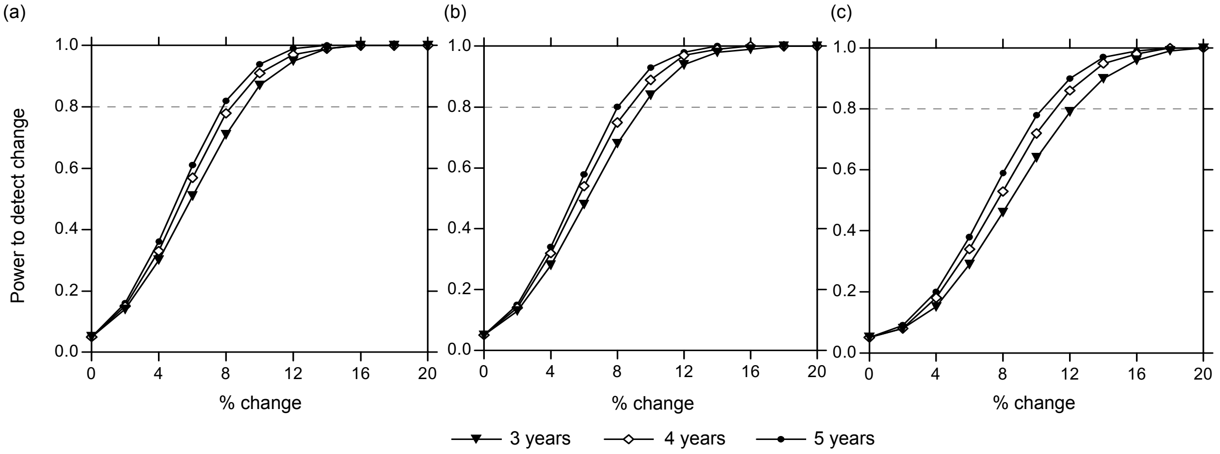

Figure 2: Power to detect a directional change in expected fledgling weight. Curves for one-tailed test for detecting directional % change from an overall mean weight of 3 139 g. Estimates presented for either: (a) 100 birds, (b) 50 birds, or (c) 30 birds each year. Change detected for three to five years of monitoring after change has taken place. Dashed line indicates power = 0.8.

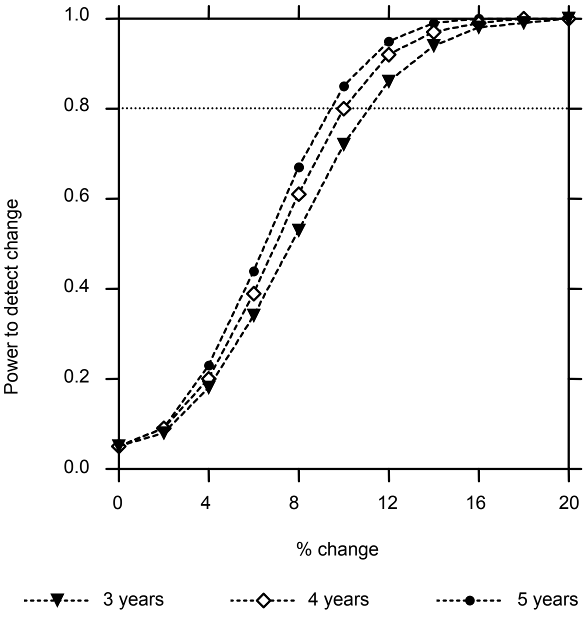

Figure 3: Power to detect a non-directional change in expected fledgling weight. Curves for two-tailed test for detecting non-directional % change from an overall mean weight of 3 139 g. Estimates presented for 50 birds weighed each year. Change detected for three to five years of monitoring after change has taken place. Dashed line indicates power = 0.8.

an impact, and whether the direction might vary between species or sites. Concordance between fledgling weight, annual breeding success and the foraging ecology of Adélie penguins at Béchervaise Island gives a clear indication that fledgling weight decreased as foraging trips became longer during the latter part of the breeding season (Emmerson et al., in prep). Fledgling weights were lower as the time taken to obtain food increased, presumably due to lower resource availability. However, other authors suggest that mean fledgling weight might actually increase in relation to a decrease in resource availability and the differential survival of one and two chick broods (Williams and Croxall, 1990; Bost and Jouventin, 1991) although this would still be recognised as a trend or step up. Given this uncertainty, it would be prudent to use two-tailed tests in power analyses for other species or populations unless there is a clear indication of a one-way directional change. In terms of the power analyses performed on the Béchervaise Island dataset, there was very little quantitative difference between results from the two-tailed and one-tailed tests. In both cases a 12% change could be identified with only three years of monitoring available after some impact, and there was limited gain from weighing more than 30 birds each year.

There is a threshold for chick fledgling weight, below which chicks will either die at the colony before fledging or their subsequent survival after fledging will be reduced. While it is unclear exactly what this threshold is, the consequences of it are high in terms of interpreting fledgling weights because of the removal from analyses of birds which die when they reach this weight as well as the potential for an increased occurrence of birds reaching this threshold in response to lowered resources. The estimate of between-year variability used in these statistical models does not take into account the year when no chicks survived to fledging (1994/95). As this is obviously an important outcome of resource availability, the provision for including the effect of total chick failure into statistical models and estimates of variability needs to be considered. Furthermore, the statistical models assume a constant variation from pre- to post-impact conditions, when in fact variation may be smaller following an impact, due to a threshold below which death occurs imposing a lower limit to measurable weight.

Conclusions

This study demonstrates the importance of estimating the magnitude of major sources of natural variability in determining the power to detect change due to some non-natural impact. For fledgling weights, the within-year component of variability was found to be substantial relative to the between-year component, but there was no evidence that the rate of change within years varied from year to year. This kind of analysis facilitates planning for optimal and cost-effective monitoring into the future, not only for the specific parameter of fledgling weight, but more generally for any parameter given pre-impact estimates of variability.

Acknowledgements

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References

Bost, C.A. and P. Jouventin. 1991. Relationship between fledging weight and food availability in seabird populations: is the gentoo penguin a good model? *Oikos*, 60 (1): 113–114.

Bunce, A., S.J. Ward and F.I. Norman. 2005. Are age-related variations in breeding performance greatest when food availability is limited? *J. Zool. Lond.*, 266 (2): 163–169.

CCAMLR. 1997. *CCAMLR Ecosystem Monitoring Program: Standard Methods for Monitoring Studies*. CCAMLR, Hobart, Australia.

Croxall, J.P. 1989. Use of indices of predator status and performance in CCAMLR fishery management. In: *Selected Scientific Papers, 1989 (SC-CAMLR-SSP/6)*. CCAMLR, Hobart, Australia: 353–365.

Emmerson, L., C. Southwell and J. Clarke. (in prep). Do Adélie penguin fledgling weights at Béchervaise Island provide an index of prey availability?

Emmerson, L.M., C. Southwell, J. Clarke and K. Kerry. 2003. Sources of variability associated with Adélie penguin CEMP parameters measured at Béchervaise Island, East Antarctica. Document *WG-EMM-03/48*. CCAMLR, Hobart, Australia.

Thompson, W.L., G.C. White and C. Gowan. 1998. Ch 5. Detection of a trend in population estimates. In: *Monitoring Vertebrate Populations*. Academic Press, San Diego: 365 pp.

Underwood, A.J. 1993. The mechanics of spatially replicated sampling programmes to detect environmental impacts in a variable world. *Austr. J. Ecol.*, 18: 99–116.

Williams, T.D. and J.P. Croxall. 1990. Is chick fledging weight a good index of food availability in seabird populations? *Oikos*, 59 (3): 414–416.

Williams, T.D. and J.P. Croxall. 1991. Chick growth and survival in gentoo penguins (*Pygoscelis papua*): effect of hatching asynchrony and variation in food supply. *Polar Biol.*, 11 (3): 197–202.

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