# Some observations on comparisons of fitting to the annual means and the observation-level data for the cases in MARAM/IWS/DEC19/Peng/P4 that support a positive effect of the island closures experiment on African penguins

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Over the course of the 12 years of the Island Closures (Feasibility Study) Experiment, Butterworth and colleagues have argued repeatedly that it is preferable to fit to annual means rather than fit to disaggregated data at the level at which the observations were collected (e.g. from individual birds or nests) and use mixed models with random effect structures that account for hierarchical sources of variation implicit to the sampling design (e.g. Butterworth & Ross-Gillespie 2019). Together with others, I have refuted this each time (e.g. Winker & Sherley 2019) as it is not consistent with modern approaches in either fisheries or ecological science (e.g. Hilborn and Liermann, 1998; Gelman and Hill, 2007; Pinheiro and Bates, 2009; Zuur et al., 2009; Thorson and Minto, 2014). Nevertheless, here I consider whether results from using the annual means remain consistent with the findings in Sherley et al. (2019, MARAM/IWS/DEC19/Peng/P4) for two cases that support a positive effect of the island closures experiment.

## Eastern Cape, Maximum distance dataset:

**1. Aggregated data (annual means).**
**Fixed component Island x Closure interaction, Year main effects (broadly equivalent to EMC; see MARAM/IWS/DEC19/Peng/P7, Appendix A):**

Rcode: glm(MD~ Closure+Island+Closure*Island+as.factor(Year), family=Gamma(link=log), data=agg)

SE for the closure main effect = 0.189
Significance test, closure effect at St Croix Island: Est = 0.41, SE = 0.189, t = 2.22, p = 0.058
Residual d.f. = 8. Parameters estimated = 14.

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**2. Aggregated data (annual means).**
**Fixed component = Island x Closure interaction, Random component = Year (broadly equivalent to EMB; see MARAM/IWS/DEC19/Peng/P7, Appendix A):**

Rcode: glmer(MD ~ Closure+Island+Closure*Island+(1|Year), family=Gamma(link=log), data=agg,)

SE for the closure main effect = 0.084
Significance test, closure effect at St Croix Island: Est = 0.387, SE = 0.084, t = 4.63, p < 0.001
Residual d.f. = 16. Parameters estimated = 6.

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**3. Disaggregated data (observation level).**
**Fixed component = Island x Closure interaction, Brood Mass main effect, Random component = Year (broadly equivalent to EMA; see MARAM/IWS/DEC19/Peng/P7, Appendix A):**

Rcode: glmer(MD ~ Closure+Island+Closure*Island+scale(CM)+(1|Year),
family=Gamma(link=log), data=MaxD)

SE for the closure effect = 0.086
Significance test, closure effect at St Croix Island: Est = 0.453, SE = 0.086, t = 5.26, $p < 0.001$
Residual d.f. = 814. Parameters estimated = 7.

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**4. Disaggregated data (observation level).**
**Fixed component = Island x Closure interaction, Brood Mass main effect, Random component = Bird ID nested in Year (broadly equivalent to eqn 2 in Peng/P4):**

Rcode: glmer(MD~Closure+Island+Closure*Island+scale(CM)+(1|Year/BirdID),
family=Gamma(link=log), data=MaxD)

SE for the closure effect = 0.098
Significance test, closure effect at St Croix Island: Est = 0.443, SE = 0.098, t = 4.53, $p < 0.001$
Residual d.f. = 813. Parameters estimated = 8.

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**5. Disaggregated data (observation level).**
**Fixed component = Island x Closure interaction, Brood Mass main effect, Random component = Island nested in Year (broadly equivalent to EMF in Peng/P8):**

Rcode: glmer(MD~Closure+Island+Closure*Island+scale(CM)+(1|Year/Island)
family=Gamma(link=log), data=MaxD)

SE for the closure effect = 0.102
Significance test, closure effect at St Croix Island: Est = 0.443, SE = 0.102, t = 3.76, $p < 0.001$
Residual d.f. = 813. Parameters estimated = 8.

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**Summary –** Precision estimates range from 2.38% to 21% larger with the disaggregated data than with the annual means (comparing to 2). All return significant and important closure effects at St Croix, as demonstrated in Peng/P4, except for the grossly over-parameterized model in 1. Inference is otherwise unchanged by the model used.

## Western Cape, Condition dataset:

Note, 2 to 5 are using the Satterthwaite (1941) approximation for the p-value from lmerTest

**1. Aggregated data (annual means).**
**Fixed component Island x Closure interaction, Year main effects (broadly equivalent to EMC; see MARAM/IWS/DEC19/Peng/P7, Appendix A):**

Rcode: lm(Condition~Closure+Island+Closure*Island+as.factor(Year), data=agg)

SE for the closure effect = 0.100
Significance test, closure effect at Robben Island: Est = −0.107, SE = 0.100, t = −1.07, p = 0.32.
Residual d.f. = 8. Parameters estimated = 14.

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**2. Aggregated data (annual means). Fixed component = Island x Closure interaction, Random component = Year (broadly equivalent to EMB; see MARAM/IWS/DEC19/Peng/P7, Appendix A):**

Rcode: lmerTest::lmer(Condition~Closure+Island+Closure*Island+(1|Year),REML=T, data=agg)

SE for the closure effect = 0.038
Significance test, closure effect at Robben Island: Est = −0.083, SE = 0.038, d.f. = 18.0, t = −2.15, p = 0.046.
Residual d.f. = 16. Parameters estimated = 6.

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**3. Disaggregated data (observation level). Fixed component = Island x Closure interaction, Brood Mass main effect, Random component = Year (broadly equivalent to EMA):**

Rcode: lmerTest::lmer(Condition~Closure+Island+Closure*Island+(1|Year),REML=T, data=Cond)

SE for the closure effect = 0.021
Significance test, closure effect at Robben Island: Est = −0.103, SE = 0.021, d.f. = 51.1, t = −4.88, p < 0.001.
Residual d.f. = 11,002. Parameters estimated = 6.

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**4. Disaggregated data (observation level). Fixed component = Island x Closure interaction, Brood Mass main effect, Random component = Bird ID nested in Year (broadly equivalent to Eqn 2 in Peng/P4):**

Rcode: lmerTest::lmer(Condition~Closure+Island+Closure*Island+(1|Year/Month),REML=T, data=Cond)

SE for the closure effect = 0.023
Significance test, closure effect at Robben Island: Est = −0.098, SE = 0.023, d.f. = 606.5, t = −4.25, p < 0.001.
Residual d.f. = 11,001. Parameters estimated = 7.

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**5. Disaggregated data (observation level). Fixed component = Island x Closure interaction, Brood Mass main effect, Random component = Island nested in Year (broadly equivalent to EMF in Peng/P8):**

Rcode: lmerTest::lmer(Condition~Closure+Island+Closure*Island+(1|Year/Island), REML=T, data=Cond)

SE for the closure effect = 0.039
Significance test, closure effect at Robben Island: Est = −0.085, SE = 0.039, d.f. = 18.3, t = −2.17,
p = 0.044
Residual d.f. = 11,001. Parameters estimated = 7.

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**Summary –** Precision estimates range from 2.63% larger to 45% smaller with the disaggregated data than with the annual means (comparing to 2). All return significant and important closure effects at Robben Island, as demonstrated in Peng/P4, except for the grossly over-parameterized model in 1. Inference is otherwise unchanged by the model used.

For this dataset, I also tried various nested and crossed random effect structures in addition to those above: (1|Month), (1|Island/Month)+(1|Year), (1|Year/Month)+(1|Island). AICc-based model selection indicated that (1|Year/Month) (as originally used in Peng/P4) was the best supported, with a DAICc = 2 over, (1|Year/Month)+(1|Island) and a DAICc = 477 over +(1|Island/Month)+(1|Year).

**Other observations:**

Comparing the chick survival dataset in the same way as above is more difficult as a model needs to be fit to the observational data to get annual chick survival estimates first, then these would need to be put back into statistical models with similar structures to those described above. In that case, the uncertainty associated with the annual estimates should really be propagated through to the estimation model to ensure accurate uncertainty in model predictions and inference (McCarthy & Masters 2005). Sherley et al. (2015) already did exactly this for the Robben Island chick survival dataset and demonstrated a positive closure effect on penguin chick survival.

Combining that observation and the results of the above, it is clear that, even with the substantial loss of statistical power that comes with the approach advocated by Butterworth and colleagues (e.g. Ross-Gillespie and Butterworth 2019), positive effects on penguins of the island closures are apparent. These effects have been apparent for a number of years (see Sherley et al. 2015, 2018). Moreover, the argument made by Butterworth and colleagues early on during the Island Closures (Feasibility Study) Experiment that fishing should benefit penguins by breaking up large schools of fish into smaller schools of fish (e.g. Robinson 2013) has been overwhelmingly refuted in recent years by empirical evidence on the foraging behaviour of these birds as revealed by animal-borne cameras (McInnes et al. 2017). In light of this, the *a priori* expectation that closures effects are equally likely be negative or positive should be reconsidered. Thus, on the basis of the results here, those in the peer-reviewed literature (Sherley et al. 2015, 2018), and those already presented to the SWG-PEL and IWS in 2019 (MARAM/IWS/DEC19/Peng/P4), I reiterate my recommendation that closures around the four focal colonies be implemented forthwith.

**References:**

Butterworth, D. S. & Ross-Gillespie, A. (2019) Is pseudo-replication biasing results from analyses from the island closure experiment which model individual penguin responses directly? Department of Environment, Forestry and Fisheries Report: MARAM/IWS/2019/PENG/P5. Pp. 1–10.

Ross-Gillespie, A. & Butterworth, D. S. (2019) Results for GLMM analyses of the South Coast penguin colony chick condition data. Department of Environment, Forestry and Fisheries Report: MARAM/IWS/2019/PENG/P3. Pp. 1–5.

Gelman, A. & Hill, J. (2007) *Data analysis using regression and multilevel/hierarchical models*. Cambridge University Press, Cambridge, UK.

Hilborn, R. & Liermann, M. (1998) Standing on the shoulders of giants: Learning from experience in fisheries. *Reviews in Fish Biology and Fisheries* 8: 273–283.

Pinheiro, J. & Bates, D. (2009) *Mixed-Effects Models in S and S-PLUS*. Springer, New York, NY.

Robinson, W. M. L. (2013) Modelling the impact of the South African small pelagic fishery on African penguin dynamics. PhD Thesis, University of Cape Town.

Ross-Gillespie A and Butterworth DS. 2019. Results for GLMM analyses of the South Coast penguin colony chick condition data. Department of Environment, Forestry and Fisheries Report: FISHERIES/2019/NOV/SWG-PEL/33. Pp. 1–5.

McCarthy, M. A. & Masters, P. (2005) Profiting from prior information in Bayesian analyses of ecological data. *Journal of Applied Ecology* 42: 1012–1019.

McInness, A. M., McGeorge, C., Ginsberg, S., Pichegru, L. & Pistorius, P. A. (2017) Group foraging increases foraging efficiency in a piscivorous diver, the African penguin. *Royal Society Open Science* 4: 170918.

Satterthwaite, F. E. (1941) Synthesis of variance. *Psychometrika* 6: 309–316.

Sherley, R. B., Winker, H., Altwegg, R., van der Lingen, C. D., Votier, S. C. & Crawford, R. J. M. (2015) Bottom-up effects of a no-take zone on endangered penguin demographics. *Biology Letters* 11: 20150237.

Sherley, R. B., Barham, B. J., Barham, P. J., Campbell, K. J., Crawford, R. J. M., Grigg, J., Horswill, C., McInnes, A., Morris, T. L., Pichegru, L., Steinfurth, A., Weller, F., Winker, H. & Votier SC. (2018) Bayesian inference reveals positive but subtle effects of experimental fishery closures on marine predator demographics. *Proceedings of the Royal Society B: Biological Sciences* 285: 20172443.

Thorson JT, Minto C. 2014. Mixed effects: a unifying framework for statistical modelling in fisheries biology. ICES Journal of Marine Science, 72: 1245–1256.

Winker, H. & Sherley, R. B. (2019) Brief reply to Butterworth and Ross-Gillespie: "Is pseudo-replication biasing results from analyses from the island closure experiment which model individual penguin responses directly?" Department of Environment, Forestry and Fisheries Report: MARAM/IWS/2019/PENG/P6. Pp. 1–5.

Zuur, A. F., Ieno, E. N., Walker, N. J., Saveliev, A.A. & Smith, G.M. (2009) *Mixed effects models and extensions in ecology with R.* Springer, New York, NY.