Model selection results for the remaining penguin metrics that can currently be fitted using an individual data approach

Richard B. Sherley[1,2]

1. Centre for Ecology and Conservation, College of Life and Environmental Sciences, University of Exeter, Penryn Campus, Cornwall, TR10 9FE, United Kingdom.
2. FitzPatrick Institute of African Ornithology, DST-NRF Centre of Excellence, University of Cape Town, Rondebosch 7701, South Africa.

Email: r.sherley@exeter.ac.uk

Here I present model selection results for the two penguin metrics from MARAM/IWS/2019/PENG/P4 (Sherley et al. 2019) that were not included in FISHERIES/2020/JUL/SWG-PEL/53REV (Sherley 2020a), Maximum foraging distance in the Western Cape and Chick condition in the Eastern Cape. I also add model selection results for Path length in the Eastern Cape. Fixed effects and error structures for Maximum foraging distance in the Western Cape and Chick condition in the Eastern Cape models are as originally specified in MARAM/IWS/2019/PENG/P4 and the 6 candidate models (different random effect structures) are as specified for the corresponding dataset from the other province in FISHERIES/2020/JUL/SWG-PEL/53REV.

As in FISHERIES/2020/JUL/SWG-PEL/53REV, model selection is based on Pareto smoothed importance sampling (PSIS) LOO cross-validation (PSIS–LOO; Vehtari et al. 2019a) and provide model averaged results based on stacking of predictive distributions (Yao et al. 2018). Bayesian implementation was as in FISHERIES/2020/JUL/SWG-PEL/53REV: All models were fit in JAGS using 3 MCMC chains of 120,000 iterations each, with the first 20,000 iterations discarded as burn-in and a thinning rate of 10, leaving 30,000 samples for inference. Unless otherwise specified, we present means and 95% highest posterior density intervals (HPDI) as the credible intervals. Convergence of all models was checked visually and using Gelman–Rubin diagnostics. All models unambiguously converged (all R-hat values ≤ 1.001).

Finally, we take the best fitting model in each case and combine them with the three best fitting models from FISHERIES/2020/JUL/SWG-PEL/53REV and convert all effect sizes to a percentage effect following the approach in Sherley et al. (2019). Note, here, for Chick Survival we have used the results with the Island × Closure interaction added back in (results are reported in Sherley 2020b, FISHERIES/2020/AUG/SWG-PEL/87). We then combine these 12 percentage effect posteriors to recalculate the Overall Closure Effect (%) first presented in MARAM/IWS/2019/PENG/P4 based on the updated results presented here and those in FISHERIES/2020/JUL/SWG-PEL/53REV. Here the posterior of the foraging datasets for the Eastern Cape are subsampled to 15,000 iterations and all other posterior samples are of length 30,000. So, each Eastern Cape foraging dataset (Maximum Distance and Path Length) are given 1/2 of the weighting of the other metrics as the two metrics are derived from exactly the same sampling process (see Sherley 2020b, FISHERIES/2020/AUG/SWG-PEL/87). Trip Duration is not used for either the Eastern Cape or the Western Cape and Path Length is not used for the Western Cape because of issues of heterogeneity of variance (Sherley 2020b, FISHERIES/2020/AUG/SWG-PEL/87).

We plot this combined distribution, and present the median, posterior mode and 95% credible intervals and the percentages of the Overall Closure Effect posterior that are above and below zero and the pre-identified 10% threshold for management action (Cochrane 2016). These are compared to the results in FISHERIES/2020/JUL/SWG-PEL/53REV below.

Results:

Maximum distance, Western Cape: The closure effect on the maximum distance travelled by foraging penguins in the Western Cape did not differ from zero at the 97.5% level at either island based on any of the candidate models, or the model averaged values (Table 1). The model averaged percentage changes were 2.4% (HPDI: –9.5 to 13.7%) at Robben and 0% (–15 to 15%) at Dassen Island. Thus, the inference that the closure had no effect on the maximum distance travelled at the Western Cape islands remains unchanged from that presented in Sherley et al. (2019).

Table 1. Model selection results for the candidate models with different random effect structures, tested to assess the impact of the fishing closures on the maximum distance travelled (km) to forage by breeding African penguins at Dassen and Robben Islands. M3 (Year/BirdID) corresponds to the original model presented in Sherley et al. (2019). Effect sizes marked in bold text are credibly different from zero (≥ 97.5% of the posterior < 0). Models are ranked by PSIS–LOO value (the *smaller* the PSIS–LOO, the better the relative model fit).

Model Number	Random effects structure	WAIC	PSIS–LOO	Stacking weight	Robben Closure effect mean (95% HPDI)	Dassen Closure effect mean (95% HPDI)
M1	Island/Year/BirdID	2864.6	3029.6	0.915	−0.028 (−0.141–0.086)	−0.006 (−0.150–0.136)
M3	Year/BirdID	2863.6	3032.3	0.065	−0.028 (−0.142–0.086)	−0.005 (−0.149–0.140)
M2	Island/BirdID	2877.1	3038.3	0.000	−0.039 (−0.151–0.077)	−0.002 (−0.147–0.141)
M6	BirdID	2877.4	3043.6	0.000	−0.040 (−0.152–0.075)	−0.002 (−0.145–0.145)
M4	Island/Year	3184.9	3185.7	0.020	0.027 (−0.320–0.393)	0.079 (−0.287–0.439)
M5	Year	3212.3	3212.7	0.000	0.025 (−0.199–0.264)	−0.057 (−0.310–0.178)
Model-averaged results					−0.027 (−0.143–0.095)	−0.004 (−0.155–0.143)

Notes: / denotes nesting of the random effects, thus Island/Year/BirdID = Month nested in Year, nested in Bird Identity. WAIC = Widely Applicable Information Criterion (Watanabe 2010). PSIS–LOO = Pareto smoothed importance sampling, leave-one-out cross-validation (PSIS–LOO; Vehtari et al. 2019). HPDI = highest posterior density interval.

Chick condition, Eastern Cape
Based on the best-fitting model (M1, Table 2) and the model-averaged result in Table 4, the closure effect on chick condition did not differ from zero at the 97.5% level at either island, although 91% of the posterior was negative at St. Croix based on the model averaged result. The model averaged percentage changes were –23% (HPDI: –23 to 10%) at St. Croix and – 8.5% (–62 to 49%) at Bird Island.

Table 2. Model selection results for the candidate models with different random effect structures, tested to assess the impact of the fishing closures on the chick condition of breeding African penguins at Bird and St. Croix Islands. Effect sizes marked in bold text are credibly different from zero (≥ 97.5% of the posterior < 0). Models are ranked by PSIS–LOO value (the *smaller* the PSIS–LOO, the better the relative model fit).

Model Number	Random effects structure	WAIC	PSIS–LOO	Stacking weight	St. Croix Closure effect mean (95% HPDI)	Bird Closure effect mean (95% HPDI)
M1	Island/Year/Month	3153.0	3153.2	0.889	−0.079 (−0.188–0.032)	−0.038 (−0.154–0.079)
M3	Year/Month	3215.4	3215.6	0.000	**−0.095 (−0.168–−0.026)**	0.052 (−0.022–0.125)
M4	Island/Month	3356.1	3356.1	0.000	**−0.062 (−0.103–−0.022)**	0.016 (−0.017–0.051)
M6	Month	3375.3	3375.3	0.052	**−0.054 (−0.094–−0.014)**	0.026 (−0.007–0.060)
M2	Island/Year	3392.0	3392.0	0.012	−0.039 (−0.203–0.127)	0.006 (−0.161–0.182)
M5	Year	3430.0	3430.0	0.046	**−0.113 (−0.193–−0.031)**	**0.132 (0.052–0.214)**
Model-averaged results					−0.078 (−0.186–0.032)	−0.026 (−0.162–0.118)

Notes: / denotes nesting of the random effects, thus Island/Year/BirdID = Month nested in Year, nested in Bird Identity. WAIC = Widely Applicable Information Criterion (Watanabe 2010). PSIS–LOO = Pareto smoothed importance sampling, leave-one-out cross-validation (PSIS–LOO; Vehtari et al. 2019). HPDI = highest posterior density interval.

Path length, Eastern Cape:
Based on the best-fitting model (M4, Table 3) and the model-averaged result in Table 3, the closure effect on Path Length did not differ from zero at the 97.5% level at either island, although 95.9% of the posterior distribution from the top model had the same sign as the mean and 96.5% of the model averaged result at St. Croix. The closure reduced the penguins' Path Lengths by 19% (−1–38%) at St. Croix based on the model averaged result, from 72 (61–84) km travelled during Open years to 58 (49–68) km during Closed years. This effects trends in the same direction as the Max. Distance effect in Sherley (2020a; FISHERIES/2020/JUL/SWG-PEL/53REV).

Table 3. Model selection results for the candidate models with different random effect structures, tested to assess the impact of the fishing closures on the path length (km) travelled by foraging African penguins at Bird and St. Croix Islands. Effect sizes marked in bold text are credibly different from zero (≥ 97.5% of the posterior < 0). Models are ranked by PSIS–LOO value (the *smaller* the PSIS–LOO, the better the relative model fit).

Model Number	Random effects structure	WAIC	PSIS–LOO	Stacking weight	St. Croix Closure effect mean (95% HPDI)	Bird Closure effect mean (95% HPDI)
M4	Island/Year	5897.8	5897.9	0.851	−0.192 (−0.411–0.026)	−0.019 (−0.222–0.178)
M5	Year	5902.0	5902.0	0.149	**−0.326 (−0.535–−0.127)**	0.082 (−0.105–0.268)
M6	BirdID	5929.8	5931.7	0.000	**−0.192 (−0.321–−0.069)**	−0.057 (−0.133–0.026)
M2	Island/BirdID	5929.9	5931.9	0.000	**−0.192 (−0.309–−0.070)**	−0.057 (−0.134–0.025)
M3	Year/BirdID	5929.8	5931.9	0.000	**−0.191 (−0.310–−0.071)**	−0.060 (−0.145–0.018)
M1	Island/Year/BirdID	5930.9	5932.8	0.000	**−0.192 (−0.313–−0.072)**	−0.052 (−0.140–0.037)
Model-averaged results					−0.214 (−0.449–0.026)	−0.004 (−217–0.207)

Notes: / denotes nesting of the random effects, thus Island/Year/BirdID = Month nested in Year, nested in Bird Identity. WAIC = Widely Applicable Information Criterion (Watanabe 2010). PSIS–LOO = Pareto smoothed importance sampling, leave-one-out cross-validation (PSIS–LOO; Vehtari et al. 2019). HPDI = highest posterior density interval.

Overall Closure Effect:
All in all, 3 effects were positive and credibly different from zero, chick survival at Dassen Island, chick survival at Robben Island and max. distance at St. Croix Island. No effects were credibly different from zero in the negative direction (Figure 1). Five percentage effect posteriors had mean effect sizes that exceeded the pre-agreed 10% thresholds for management action (Figure 1) and a further one (chick survival at Robben Island) had a mean effect size of 9.8%; five of these six effects were positive with > 95% probability (Figure 1). In contrast, two percentage effect posteriors had mean effect sizes more negative than −10% (chick condition at St. Croix and Bird Island), but neither was negative with > 95% probability (Figure 1).

Recalculating the Overall Closure Effect to include the best fitting models from Table 1–3 with the best fitting models from FISHERIES/2020/JUL/SWG-PEL/53REV has reduced the evidence for a biologically meaningful closure effect slightly (Table 4), although the posterior mode (most probable part of the distribution, the peak in Figure 2) remains close to the 10% threshold at 9.5% (compared to 11.4% in Sherley et al. 2019) and ~70% of the posterior distribution is > 0%. Overall, there is still more than twice the evidence for a closure effect than no closure effect and for a closure effect exceeding 10% relative to the evidence for a −10% effect (Table 4).
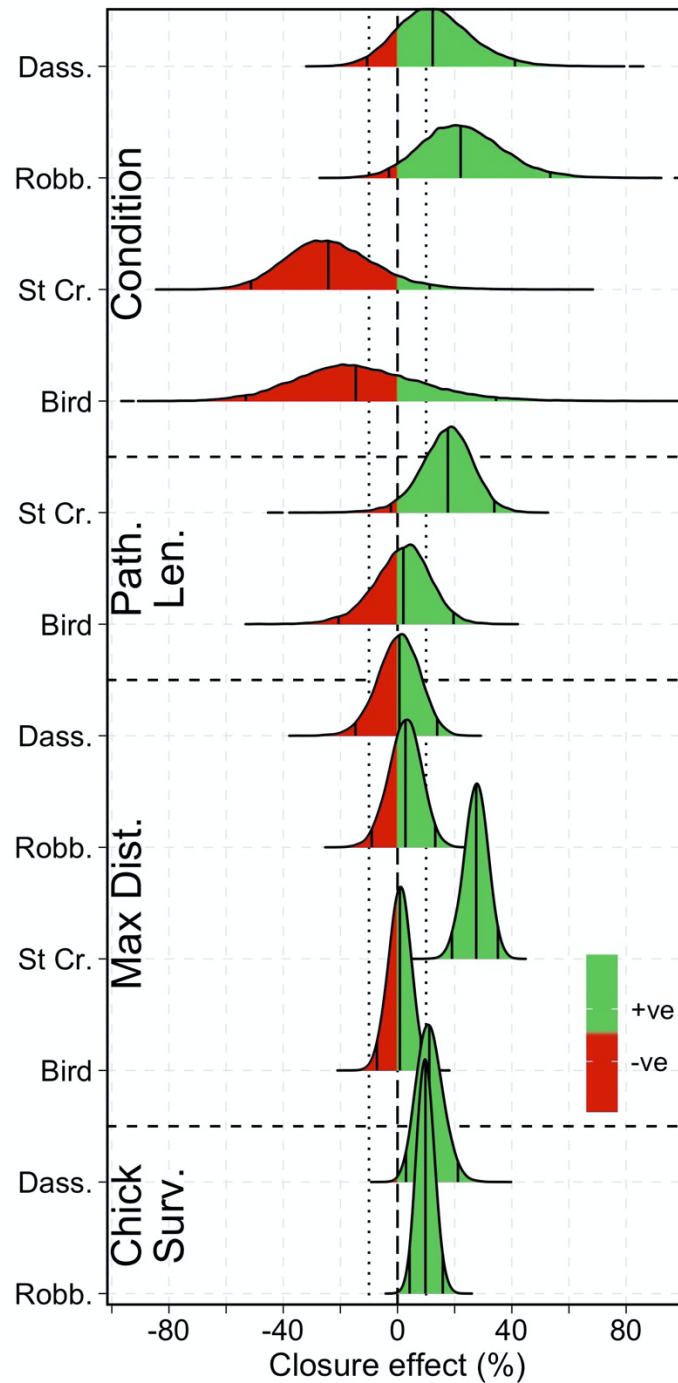
Figure 1. Posterior distributions for the percentage difference between 'Closed' years and 'Open' years for chick body condition [Condition], the maximum distance travelled from the island by foraging penguins [Max. Distance], the path length travelled by foraging penguins [Path Len.] and chick survival [Chick Surv.] at Dassen Island [Dass.], Robben Island [Robb.], Bird Island [Bird] and St Croix Island [St Cr.]. The mean and 95% credible intervals are shown on each posterior distribution as solid black lines. The zero axis (no effect of closure) is shown as a dashed black line. The pre-agreed 10% (or −10%) thresholds for management action are shown as dotted black lines. All posterior samples yielding a positive % effect for penguins are shown in green [+ve] and those yielding a negative % effect of the closure on the penguins are shown in red [−ve]. Chick body condition index results for Dassen Island and Robben Island, and maximum distance travelled by foraging penguin results for St Croix Island and Bird Island are based on the best fitting models in Sherley (2020a; FISHERIES/2020/JUL/SWG-PEL/53REV). Chick body condition index, path length results

for St Croix Island and Bird Island, and maximum distance travelled by foraging penguin results for Dassen Island and Robben Island are based on the best fitting models presented here (Tables 1–3). Chick survival results for Dassen Island and Robben Island are based on the model with the Island × Closure interaction requested by Bergh (2020); see Sherley (2020b) for those results.
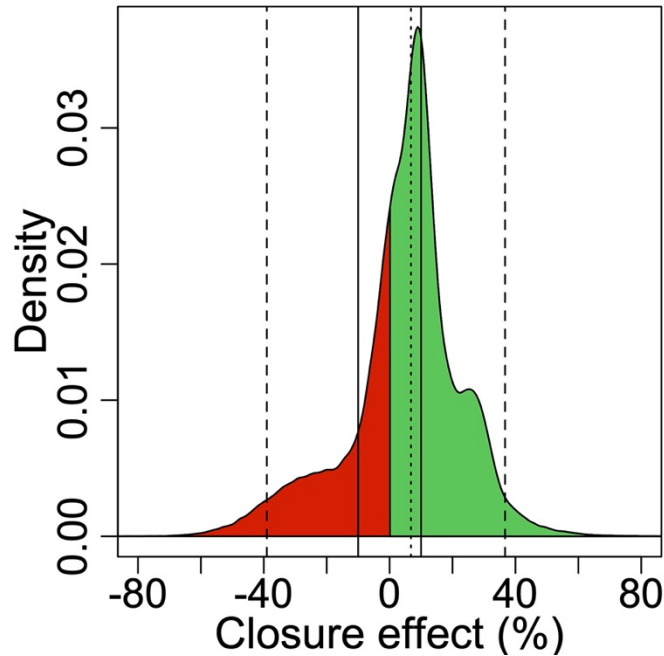

Figure 2. Posterior distribution (polygon), median (dotted black line) and 95% HPDI (dashed black lines) for the Overall Closure Effect (%), the overall difference between 'Closed' years and 'Open' years based on combining the 12 individual posteriors in Figure 1. The solid black lines show a pre-agreed 10% (or −10%) threshold for management action.

The four posterior distributions for path length and maximum distance at the Eastern Cape Islands were each subsampled to 15 000 posterior samples. The remaining 8 individual posteriors distributions have equal weighting (30 000 posterior samples). All samples yielding a positive % effect for penguins are shown in green [+ve] and those yielding a negative % effect of the closure on the penguins are shown in red [−ve]. Chick body condition index results for Dassen Island and Robben Island, and maximum distance travelled by foraging penguin results for St Croix Island and Bird Island are based on the best fitting models in Sherley 2020a; FISHERIES/2020/JUL/SWG-PEL/53REV). Chick body condition index, path length results for St Croix Island and Bird Island, and maximum distance travelled by foraging penguin results for Dassen Island and Robben Island are based on the best fitting models presented here (Tables 1–3). Chick survival results for Dassen Island and Robben Island are based on the model with the Island × Closure interaction requested by Bergh (2020; FISHERIES/2020/AUG/SWG-PEL/84); see Sherley (2020b; FISHERIES/2020/AUG/SWG-PEL/87) for those results.

Table 4. Comparison of the Overall Closure Effect presented in Sherley et al. (2019), Sherley (2020a) and the one calculated here.

Parameter	Sherley et al. 2019	Sherley (2020a)	This report
Median (%)	8.5	8.7	6.8
95% HPDI (%)	(−36–45)	(−36–40)	(−39–37)
% positive (>0)	71.7	75.2	69.2
Ratio of evidence for a closure effect	2.53	3.03	2.25
% exceeding management threshold (>10%)	44.3	44.3	38.0
Ratio >10% to <−10%	3.69	3.96	2.39

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