Simulation model for evaluating the power of tagging data coupled to a forage area fishing closure experiment to determine the extent to which closure might impact penguin survival

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A systematic penguin tagging programme has been proposed with the aim of correlating annual penguin survival estimates with whether or not pelagic fishing is excluded from the neighbourhood of an island in a year. A key parameter in the programme design is the number of new birds to be tagged annually. This paper outlines the simulations which will show how this number affects the power of a tagging programme to detect a difference in survival rates under different fishing treatments.

I. PENGUIN POPULATION PROJECTION

The age-structured production model described in Robinson and Butterworth (2009) is projected forwards in time to simulate future penguin abundance. The equations are repeated here for easy reference.

The number of female penguins $N_{y,a}$ in year y of age a is determined by the following equations:

$$N_{y+1,a} = \begin{cases} H_y \sum_{k=4}^{A} N_{y,k} & \text{if } a = 0 \\ N_{y,a-1} e^{-M_y} & \text{if } 1 \leq a < A \\ \left(N_{y,a-1} + N_{y,a}\right) e^{-M_y} & \text{if } a = A \end{cases} \tag{1}$$

The symbols are defined as follows:

$H_y \sim \mathcal{N}(\mu_{\mathrm{b}}, \sigma_{\mathrm{b}}^2)$ is the random breeding success and first year survival effect in year y,

A is the plus-group age, and

M_y is the natural mortality rate in year y.

See Table I for the values of μ_{b} and σ_{b}. The number of adult females each year is:

$$\bar{N}_y = \sum_{a=2}^{A} N_{y,a} \tag{2}$$

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Iterations run for the years 2009 to 2030.

II. MORTALITY INCORPORATING FISHING EFFECTS

The mortality rates are modelled with the equation:

$$M_y = F_y(0.02 + Z_y) \tag{3}$$

where F_y is the fishing effect which (under the assumption for these simulations) lowers the mortality rate by 20% when the island is closed to fishing, which we assume happens in alternate years so that:

$$F_y = \begin{cases} 1 & \text{when } y \text{ is even} \\ 0.8 & \text{when } y \text{ is odd} \end{cases} \tag{4}$$

$Z_y \sim \text{Log-}\mathcal{N}(\mu_\mathrm{m}, \sigma_\mathrm{m}^2)$ are log-normally distributed random effects in annual mortality.

Figure 1 shows examples of typical penguin population trajectories for the two treatments under consideration: no closures, and closures every second year. Both plots show considerable variability resulting in a wide spread of possible abundances by 2030, but the mean abundance is higher for the case with closures.

III. FUTURE TAGGING

In the simulation, T birds are tagged each year, starting in 2010. The value of the parameter T is given as a model input.

IV. SIMULATED OBSERVATIONS

A. Moult counts

Each future year, the simulated number of observed adult female moulters is

$$N_y^\mathrm{obs} = \bar{N}_y e^{\rho_y}, \qquad \rho_y \sim \mathcal{N}(0, \sigma_c^2) \tag{5}$$

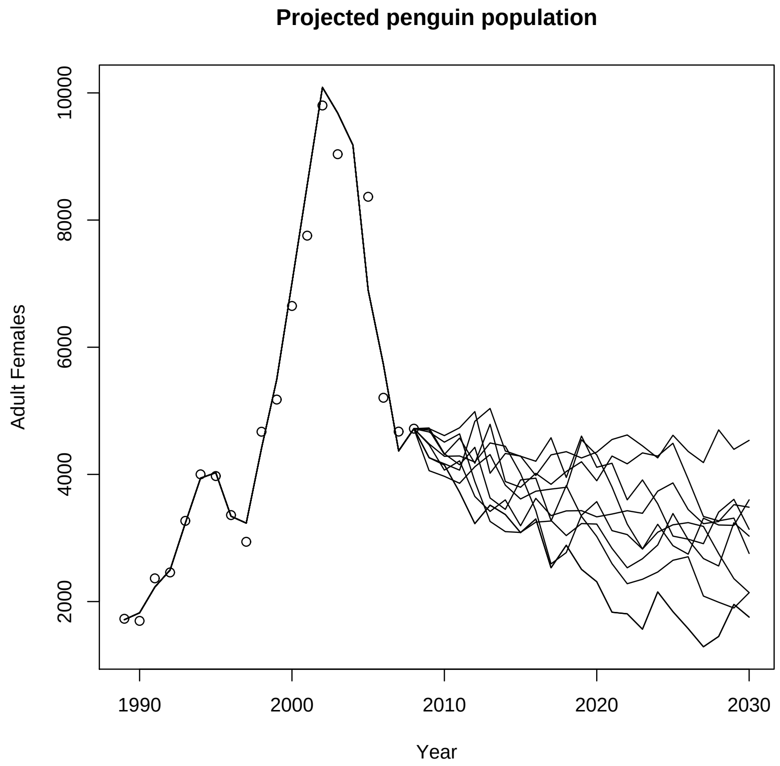
B. Tag sightings

The probability p_y of sighting each year is assumed to be Normally distributed:

$$p_y \sim \mathcal{N}(\mu_p, \sigma_p^2)$$

The number of penguins tagged in year t available to be sighted in year y is

$$n_{t,y} = T_t \exp\left(-\sum_{i=t}^{y-1} M_i\right) \tag{6}$$



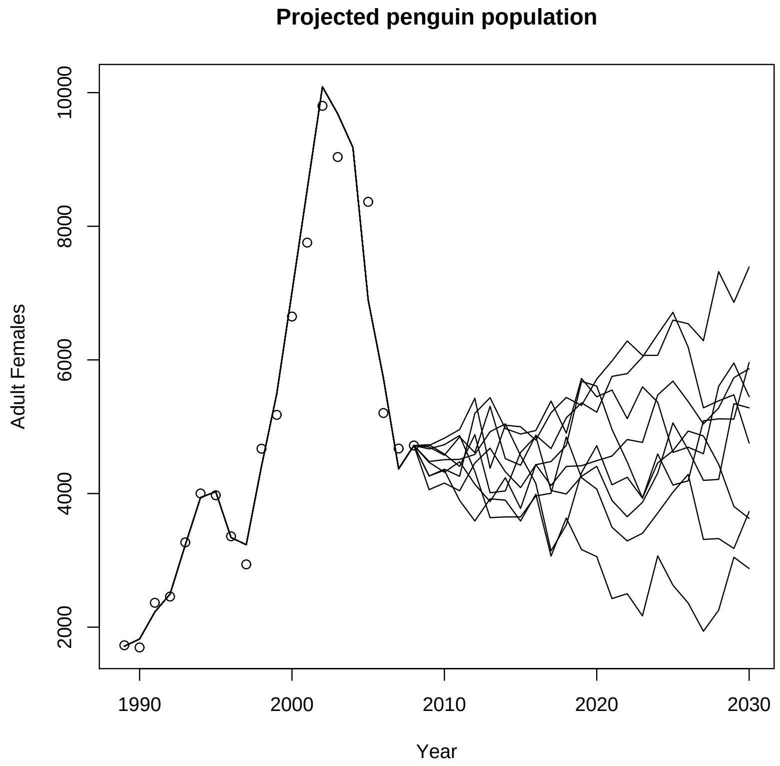


Fig. 1 Worm plots showing several typical penguin population trajectories for Robben Island with no closures (top) and closures in alternate years (bottom). Historic moult counts are shown with open circles.

TABLE I Initial proposed inputs to the penguin tagging simulation model. The distribution parameters have been chosen based on the results of the model fits previously obtained.

Constant	Symbol	Value
Mean breeding success and first year survival	μ_{b}	0.6
Standard deviation of breeding success and first year survival	σ_{b}	0.2
Mean of the logged mortality rates	μ_{m}	$\ln 0.25$
Standard deviation of the logged mortality rates	σ_{m}	0.2
Standard deviation of simulated moult count residuals	σ_{c}	0.2
Mean of the annual probability of sighting	μ_{p}	0.25
Standard deviation of the annual probability of sighting	σ_{p}	0.05
Plus-group age	A	10
Number of birds tagged each year	T	200

Assuming a Poisson process, the expected number of sightings in year y of birds tagged in year t is

$$\eta_{t,y} = n_{t,y} p_y \tag{7}$$

Next, a random number r is drawn from the standard uniform distribution $\mathcal{U}[0,1]$. The simulated number of sightings in year y of birds tagged in year t is $m_{t,y} = s$ where s is the largest integer such that:

$$\sum_{k=0}^{s} \frac{e^{-\eta_{t,y}} \eta_{t,y}^{k}}{k!} < r$$

V. POWER ESTIMATION

The proposed values of inputs to the tagging simulation model are given in Table I. For each future data set generated, the mortality rates each year $\hat{M}_y$ will be estimated using the method of Robinson and Butterworth (2009). The geometric average of the estimated mortality rates for the years with and without fishing will be calculated. For each simulation run, the difference between these average mortalities will be calculated:

$$\Delta\bar{\hat{M}} = \bar{\hat{M}}_{\mathrm{f}} - \bar{\hat{M}}_{\mathrm{nf}} \tag{8}$$

After running a large number of simulations, a histogram of these differences will be produced. The width of this histogram will indicate the precision with which the fishing effect can be detected. Thus, for example, if much of the histogram overlaps zero, the power of the experiment is low.

REFERENCES

Robinson, W. and D. S. Butterworth. 2009. *Fitting both moult counts and tagging data to a population model for Robben Island penguins.* Document MCM/2009/SWG-PEL/33.