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Supplementary material

Costs and effectiveness of damage management of an overabundant species (*Sus scrofa*) using aerial gunning

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Supplemental Information S1: Removal model details with covariates on capture rate.

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This is a standard removal model (Zippin, 1958) accounting for varying in effort (Davis *et al.*, 2016) implemented using data augmentation version (Tanner & Wong, 1987). The data are of the form y_{ijk}, where $y_{ijk} = 1$ represents individual 'k' being removed from site 'i' during removal pass 'j'. The total number of sites is 'n', the total number of passes per site is 'J', and the total number of potential individuals in site 'i' is 'm_i'. As this is a data augmentation model z_{ik} is an indicator of an individual being in the population or not, modeled with a Bernoulli distribution with probability ψ_i. We restricted individuals from being included in the population after they were removed by using an indicator for previous removal.

The removal effort (e.g., hours in the helicopter) for each site 'i' and pass 'j' is denoted by g_{ij}. The site-level removal probability is denoted by θ_i, and the removal rate accounting for effort is denoted by p_{ij}. The capture rate for one unit of effort (θ_i) is modeled with covariates using a logit link. The covariates shown in the model below are $Team$ indicating the pilot/gunner personnel team, and $\%cover$ indicating the amount of canopy cover in the study area i.

The MCMC algorithm for this model uses a Gibbs sampler with a Metropolis-Hastings step for $[\theta_i|\bullet]$ (see Gelman et al. 2013 for implementation details). The hyperparameters for $\alpha_\psi, \beta_\psi, \alpha_\theta, \beta_\theta$ are 1, 2, 1, and 2 respectively. They were chosen to be relatively uninformative. The results were insensitive to the choice of these priors.

Model

$$
\begin{aligned}
y_{ijk} &= \begin{cases} 0 & , z_{ik} = 0 \\ \begin{cases} Bern(p_{ij}) & , \sum_{l<j} y_{ilk} = 0 \\ 0 & , \sum_{l<j} y_{ilk} > 0 \end{cases} & , z_{ik} = 1 \end{cases} \\
& i = 1, ..., n \quad \text{(sites)} \\
& j = 1, ..., J \quad \text{(removal passes)} \\
& k = 1, ..., m_i \quad \text{(potential individuals at site i)} \\
z_{ik} &\sim Bern(\psi_i) \\
\Psi_i &\sim Beta(\alpha_\Psi, \beta_\Psi) \\
p_{ij} &= 1 - (1 - \theta_i)^{g_{ij}} \\
logit(\theta_i) &= \boldsymbol{X} * \underline{\beta} \\
\boldsymbol{X} * \underline{\beta} &= \beta_0 + \beta_1 * Team + \beta_2 * \%cover \\
\beta_{0,1,2} &\sim N(0, \sigma_\beta^2)
\end{aligned}
$$

Joint Distribution

$$
[\boldsymbol{z}, \boldsymbol{\psi}, \boldsymbol{\theta} | \boldsymbol{y}, \boldsymbol{g}, \boldsymbol{X}] \propto \prod_{i=1}^{n} \prod_{j=1}^{J} \left[\prod_{k=1}^{m_i} \Big([y_{ijk} | p_{ij}]^{z_{ik}} 1^{(1-z_{ik})} [z_{ik} | \psi_i] \Big) [\psi_i | \alpha_\psi, \beta_\psi][\theta_i | \sigma_\beta] \right]
$$

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