Preliminary Results from Pukenui Goat Control Analysis Using Bayesian Methods

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Manaaki Whenua

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1. Introduction

Feral goats are patchily distributed over about 14% of New Zealand (Parkes 2005) with several hundred more-or-less discrete populations, of which about 150 are under some sort of control (Parkes 1993). Common management questions include: what are the target densities for these controlled populations, what is the efficacy of different control measures, and how often and how intensively should the ongoing maintenance control be applied given in situ breeding and immigration?

Under the Envirolink funding programme, Northland Regional Council asked Landcare Research to utilise data collected from one isolated goat population under ground-hunting control at Pukenui Forest (near Whangarei) as a template to answer the second of these management questions: how many goats are left after control?

2. Background

Feral goat populations can be reduced to zero or near-zero in many places in New Zealand. However, whether eradication is achievable often depends on how isolated the population is from potential sources of immigration by new goats. In all cases where there are either residual animals or immigrants, managers have to decide how often and how intensively to apply maintenance control to keep the goats at zero or low levels.

This requires some judgements about, firstly, whether the control has achieved these low levels, and secondly, some assurance that no or very few goats is sufficient to allow recovery of the biodiversity assets at the site. Following a discussion with Northland Regional Council, DOC and Pukenui Trust staff we resolved to adapt the Bayesian analysis methods developed for the feral pig eradication on Santa Cruz Island (Ramsey et al. 2008) and control/extirpation on reserves on Maui and Molokai islands (Barron et al. 2009) to address the first of these questions for the goat control programme in Pukenui Forest.

3. Objectives

- In a preliminary analysis determine the relationship between hunting effort and the probability of detecting a goat and estimate the number of goats remaining in Pukenui Forest following initial control efforts.

4. Methods

Shapefiles were provided by the Pukenui Trust via DOC detailing the Pukenui Forest boundaries, the tracks generated by the hunters as they searched for goats, and the location of goat kills. Goat hunting was conducted from 1 March 2009 to 28 June 2009. For the purposes of analysis this hunting effort was divided into four monthly hunting periods. The hunters' tracks for each monthly hunting period appeared to cover most of the reserve, nominally satisfying the assumption that all goats are at risk within a hunting period. For each hunting period, the number of goat kills and the hunters' track lengths were tallied. Summed track lengths (km) were divided by the area of the reserve (km^2) to give a measure of hunting effort per period (km/km^2).

The hunting effort and goat kill data were used to estimate the initial goat population size (N) and the probability of detecting (and killing) a goat (θ) for a given level of effort using a Poisson catchability model (Seber 1982):

$$\theta_i = 1 - \exp(-\rho G_i) ,$$

where G_i is the hunting effort in period i and ρ is the catchability coefficient, which is assumed to be constant over all hunting periods. Linearising the above equation we get:

$$\log[-\log(1-\theta_i)] = \log(\rho) + \log(G_i) + \varepsilon .$$

To account for unexplained variation in the detection probability we have included an overdispersion parameter, ε, which is assumed to be normally distributed with a mean of zero and a variance of σ^2:

$$\varepsilon \sim N(0, \sigma^2) .$$

If each goat has the same probability of detection during a hunting period θ_i, then the number removed during that period, n_i, will be binomially distributed:

$$n_i \sim \text{Binom}(\theta_i, N-x_i) ,$$

where $N-x_i$ is number of goats available being the initial population size decremented by the cumulative number of goats killed to date.

The model parameters were estimated using Bayesian analysis which involves updating "prior" probabilities or beliefs about the model hypothesis (parameter values) with the observed data to give a revised or "posterior" probability of the hypothesis in light of the data. Parameter values are expressed as probability distributions, usually described by their mean or median and a 95% credible interval which is the region about the centre of the parameter's distribution in which 95% of the probability lies. Because we did not have any prior information on the parameter values, we used deliberately "vague" priors which made no strong assumptions about what the parameter values were likely to be. Estimating a model parameter in a Bayesian framework requires integrating across all the other parameters in the model, which can be difficult to compute, thus for multi-parameter models a numerical sampling technique called Markov chain Monte Carlo (MCMC) is often used. We used MCMC sampling as implemented by the WinBUGs software (version 1.4) to estimate the model parameters. The MCMC was run with three parallel chains for 80 000 iterations to obtain parameter convergence, which was indicated when scale reduction factors R < 1.05 (Gelman & Rubin 1992). After first ensuring the chains were well mixed, posterior summaries of the parameter values were taken from three chains containing 20 000 samples, with a thinning rate of five (i.e. 12 000 samples).

5. Results

A total of 228 goats were shot over the four months of hunting. Hunting effort and goat kills per month are summarised in Table 1. Plotting catch per unit effort (CPUE) against cumulative catch shows a linear relationship indicating that the assumption that one unit of effort catches a fixed proportion of the population is satisfied (Fig. 1).

The median posterior value for *N*, the initial number of goats in the reserve, was 268 (95% credible interval: 247–307; Table 2), indicating 85% of the goats in the reserve had been detected and shot to date. Figure 2 shows how the probability of detecting (and shooting) a goat increases with hunting effort. Note the variability around the relationship due to overdispersion (σ; Table 2) and uncertainty in parameter estimates. For the average hunting effort expended per month (G = 9 km/km^2) this relationship gives an estimated detection probability of 0.37. To obtain a detection probability of 0.95, hunting effort would have to be substantially increased to around G = 58 km/km^2.

Table 1 Hunting effort and goat kills per month in Pukenui Forest, March–June 2009.

	March	April	May	June
Effort (km/km^2)	10.96	7.36	10.31	8.44
No. goats killed	124	37	41	26

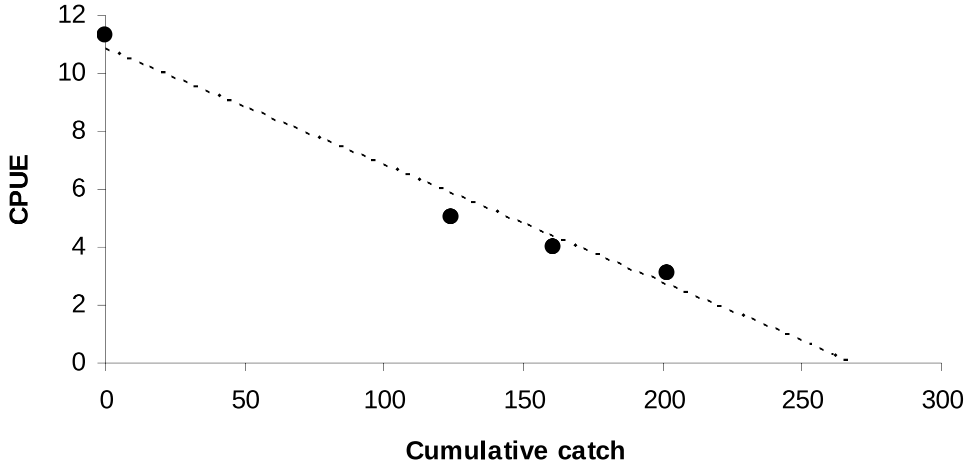

Fig. 1 Observed (black dots) and fitted (dashed line) relationship between catch per unit of effort (CPUE = goats-killed/effort) and cumulative number of goats killed in Pukenui Forest.

Table 2 Parameter estimates and their credible intervals

Parameter	Median	2.5% CI	97.5% CI
N	268	247	307
ρ	0.0519	0.0355	0.0757
σ	0.1160	0.0522	0.4440

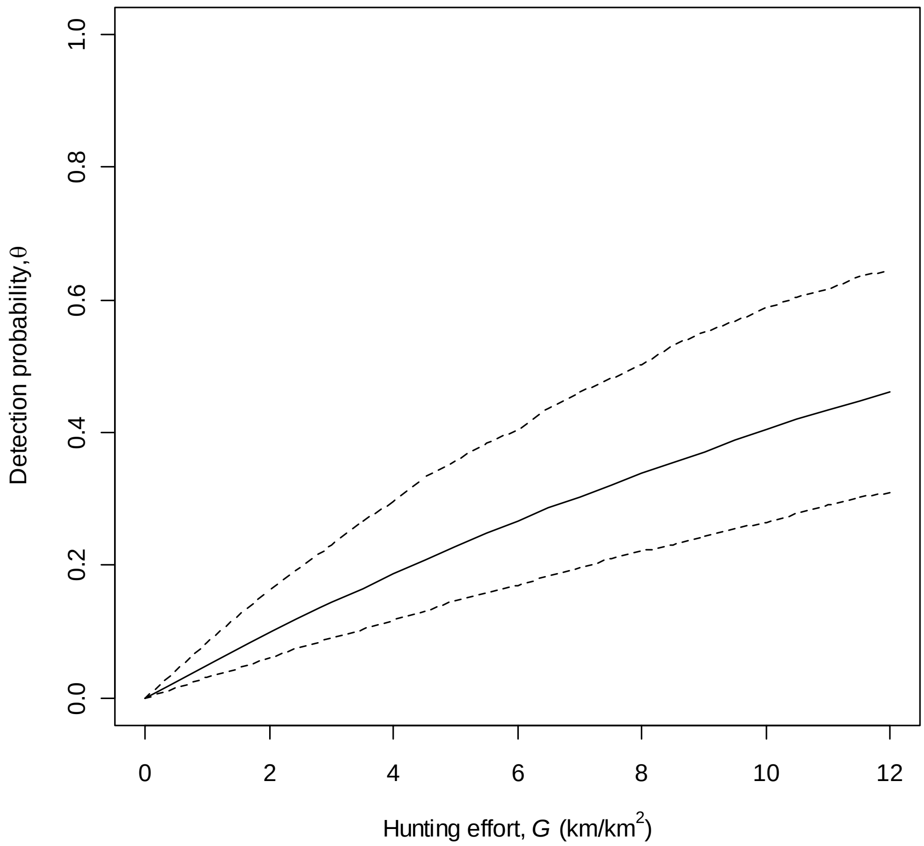

Fig. 2 Probability of detecting and shooting a goat (θ) given hunting effort G. Dashed lines are 95% credible intervals.

6. Discussion

This preliminary analysis has determined the relationship between hunting effort and the probability of detecting and shooting a goat in the Pukenui Forest. Should control progress to the stage where no more goats are found, we can use this information to estimate the probability that there are no goats remaining. Similarly, given our estimated goat detectability we can also try out different scenarios such as how much more hunting effort would be required to be 95% confident no goats remain? The analysis also simultaneously estimates the initial number of goats in the reserve, which enabled calculation of the hunting efficacy to date, which was approximately 85%.

As with any model we have made some simplifying assumptions, for example, that each individual goat has the same probability of detection and that the system is closed and the only change in population abundance is due to culling. If we wish to incorporate future hunting data into the analysis we will have to adapt the models to include increases in numbers due to reproduction of survivors and possibly immigration.

It would be useful to perform similar analyses across a range of goat populations under control.

7. Acknowledgements

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