Goat eradication program, Dirk Hartog Island – analysis of results to November 2017

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Executive summary

Based on the results of 20 successive surveys, it is estimated that the likelihood that goats have been successfully eradicated from Dirk Hartog Island is 98.6% (with 95% confidence interval 98.2 – 99.0%).

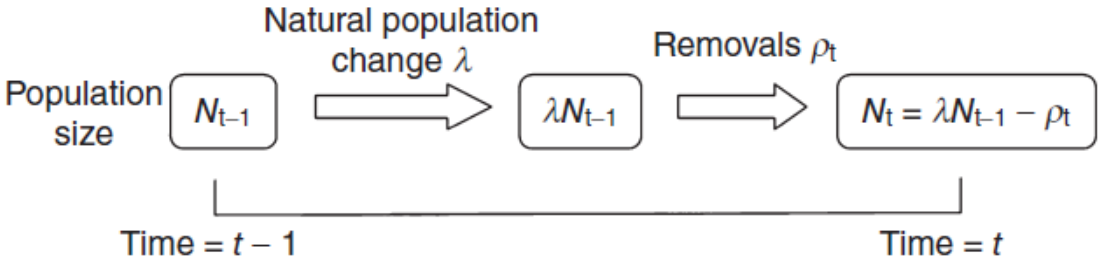
Background and aims

In an eradication program, the target population is progressively reduced to the point where individuals can no longer be detected. At this stage, a decision must be made whether the existing data is sufficient, or additional surveillance is needed, to confirm that eradication has been achieved (Ramsey et al., 2011). Surveys to detect and destroy goats on Dirk Hartog Island commenced in February, 2010. No goats have been detected on the island in the six successive surveys since November 2015. To estimate the likelihood that goats have been successfully eradicated from the island, a statistical analysis of these results has been conducted. The detectability of goats was estimated and the likelihood that goats have been eradicated determined.

Methods

In a population that is subject to successive removal of individuals, the size of the population at any given time is determined by the initial population size, natural changes (due to breeding, deaths, emigration and immigration), and changes due to the removal of individuals. The changes can be measured by the population growth rate (λ) and the number of animals removed (ρ), respectively (Fig. 1). For the goat population on Dirk Hartog Island, both immigration and emigration are nil, although there may be some population increase due to breeding (S. Heriot, pers. comm.). The number of deaths from natural causes is irrelevant to determining eradication success, as any animals that die naturally are never detected and can be excluded from the population estimate. The number of removals is the number of animals destroyed during each survey.

Figure 1. Schematic representation of changes in the size of the goat population on Dirk Hartog Island from time *t-1* to time *t* (after Rout et al., 2014).



Generally, surveys can never provide absolute certainty that a species is absent from a location (MacKenzie, 2005). The species may be absent, or one or more individuals may be present but not detected. This imperfect detectability is measured by the detectability rate (p), which varies depending on the species and other factors, such as search effort or weather conditions.

In a removal experiment, if the initial population size (N_0) is unknown it can be estimated using an appropriate statistical model (Farnsworth et al., 2002). The number of animals detected and removed (R) during each survey is:

$$R_t = p_t N_{t-1}$$

And the size of the population remaining after the animals are removed is:

$$N_t = N_0 - \Sigma R_{i \leq t}$$

It follows that:

$$R_t = p_t (N_0 - \Sigma R_{i \leq t-1})$$

And this is the form in which the model is fitted (Appendix 1).

The detectability rate can be assumed to be constant for each survey or can be modelled as a function of covariates (St. Clair, et al., 2013). The population size (N) and detectability (p) are assumed to have Poisson and Bernoulli distributions, respectively. The number of goats removed during each survey has a Binomial distribution with mean Np.

Using this model, the initial population size (N_0) and detectability of goats on Dirk Hartog Island were estimated using Poisson regression. In this study, 'detectability' is used in a broader than usual sense as the probability that a goat is both detected and destroyed. A small flock of collared ('Judas') goats, which were used to attract other goats, were present during the study but these have been excluded from the analysis and the results apply only to uncollared goats. The models were fitted using the *glimmix* procedure of the software package SAS (SAS Institute Inc., 2011; Appendix 1).

Results

Each year, two (2010 – 2013) or three (2014 – 2017) helicopter surveys have been conducted and, to date, 20 surveys have been completed with a total of 6,981 goats destroyed (Table 1). It is apparent from Table 1 that flight time may not be a good measure of survey effort as the varying amount of time needed to destroy the goats (and some sheep) during each survey, rather than time actually spent searching for goats, is a complicating factor. The amount of search time effectively lost during each survey is unknown but likely to be substantial, particularly during the first two surveys when several thousand animals were destroyed. The results of the second survey indicate either an increase in detectability or natural population increase. It is also plausible that detectability increased after the initial survey because of increased effectiveness in locating and destroying goats following experience from the first survey. Excluding the initial survey from the analysis was therefore examined, to determine if this improved model fit for the remaining surveys.

Table 1. Results of the sheep and goat eradication program, Dirk Hartog Island, February 2010 – November, 2017. Helicopter flight time provides a potential estimate of search effort.

Date	**Survey (t)**	**Flight time**	**Goats destroyed[1]**	**Sheep destroyed**
Feb, 2010	1	2500	2519	60
Aug, 2010	2	2000	3029	59
Jan, 2011	3	2400	475	3
Aug, 2011	4	1800	310	0
Jan, 2012	5	1550	140	0
Sept, 2012	6	1600	203	0
Feb, 2013	7	1350	53	2
Sept, 2013	8	2529	104	0
Jan, 2014	9	2025	80	0
Jun, 2014	10	1188	39	0
Oct, 2014	11	1544	19	0
Feb, 2015	12	1644	5	0
Jun, 2015	13	1544	1	0
Nov, 2015	14	1646	4	0
Feb, 2016	15	1334	0	0
Jun, 2016	16	1279	0	0
Nov, 2016	17	1742	0	0
Feb, 2017	18	1898	0	0
Jun, 2017	19	1262	0	0
Nov, 2017	20		0	0
Totals			**6981**	**124**

[1] Excludes collared ‘Judas’ goats

Using all of the survey results, the initial size of the goat population on Dirk Hartog Island was estimated (± standard error) to be 6,979 ± 118 individuals; this estimate is very close to the total number of goats that have since been destroyed (Table 2). The average detectability rate was 0.443, indicating that, on average, a single survey had a 44.3% chance of detecting an individual goat. Excluding the first survey, however, resulted in a substantially higher detectability (0.509) and reduced overdispersion. Direct comparison of the two models is not possible as they are based on different data, but it is likely that the estimates excluding the first survey are more accurate.

Given that there have been six successive surveys since the last goat was detected on the island, in November 2015, the likelihood that one or more goats have persisted on the island but remained undetected is:

P(Goats still present | six successive surveys with no detections) = $(1 - 0.5086)^6 = 0.014$

The complementary probability, that no goats remain on the island, is 0.986 with 95% confidence interval [0.982 – 0.990]. The estimated likelihood that goats have been successfully eradicated from the island is therefore 98.6 ± 0.4%.

Table 2. Parameter estimates of the Poisson regression model of goat population size on Dirk Hartog Island and their estimated initial (pre-February, 2010) abundance (N_0), based on all 20 surveys up to November 2017 (a); and excluding the first survey (b). The estimated standard errors of the initial population estimates use the formula for the variance of a ratio. Standard errors adjusted for overdispersion have been scaled by the Pearson χ^2 value. Fit statistics for each model are: (a) deviance = 843.6 on 18 df, AICc = 927.2, overdispersion (scaled Pearson χ^2 = 49.4); (b) deviance = 649.5 on 17 df, AICc = 723.5, overdispersion (scaled Pearson χ^2 = 36.2).

Parameter	Estimate	Standard error	SE adjusted for overdispersion
(a) Based on surveys 1 – 20			
Intercept (N_1)	3091.5	37.07	260.4
Detectability	0.443	0.00531	0.0373
Initial abundance (N_0) = Intercept/detectability	6978.6	118.4	831.6
(b) Based on surveys 2 – 20			
Intercept (N_1)	3549.1	53.24	320.1
Detectability	0.509	0.00763	0.0459
Initial abundance (N_0) = Intercept/detectability	6978.1	148.1	890.7

In interpreting these results, it is essential to give due consideration to the assumptions underlying the statistical model used in this study. Some of these are discussed in this report, but detailed discussion of the assumptions and the consequences of their violation are given by MacKenzie et al. (2002), MacKenzie (2005) and Rout et al. (2009, 2014). There are also potential limitations in the assumptions specific to this study. For example, it is possible that some individual goats are not susceptible to detection using the helicopter search method, or that animals show a behavioural response to successive surveys so those that remain after each removal episode are progressively more difficult to detect. These potential limitations and their consequences are discussed by Ramsey et al. (2009, 2011), Ramsey and Will (2012) and Gregory et al. (2014).

References

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Appendix 1.

SAS code for estimating a Poisson regression model of goat detectability and abundance on Dirk Hartog Island, February 2010 – November 2017.

```
data a;
 do i=1 to 20;
  input shot cshot time;
* 'shot'  is the number of animals shot during this survey;
* 'cshot' is the cumulative number of animals shot during previous surveys;
* 'time' is the time spent searching during this survey;
  output;
 end;
cards;
2519 0 2500
3029 2519 2000
475 5548 2400
310  6023 1800
140 6333 1550
203 6473 1600
53 6676 1350
104 6729 2529
80 6833 2025
39 6913 1188
19 6952 1544
5 6971 1644
1 6976 1544
4 6977 1646
0 6981 1334
0 6981 1279
0 6981 1742
0 6981 1898
0 6981 1262
0 6981 .;


data b;
 set a;
* remove initial survey ('i' is the sequential survey number);
if i<2 then delete;

* estimation without CPUE;
proc glimmix data=c;
  model shot = cshot / dist=p link=id solution;
  output out=z predicted=p_mix lcl=l_mix ucl=u_mix;
run;

proc print;

run;
```