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SHORT COMMUNICATION

INDICES OF DENSITY OF FERAL GOATS IN A GRASSLAND/ FOREST HABITAT, MARLBOROUGH, NEW ZEALAND

Summary: Hourly kill-rates and encounter-rates for hunters of feral goats *(Capra hircus)* provided linear indices of goat population size in a 638 ha area of forest and grasslands in Marlborough. The goat population of about 108 animals was reduced to near zero in 105 hours of hunting effort on 11 days at a cost of about \$8.20 ha^{-1}. However, goats from the surrounding areas soon recolonised the study area as 19 were shot in 21 hr and 14 in 24 hr 10 and 13 months after the study, respectively. These kill-rates suggest the population had recovered to 30 - 40% of its original size after 10 months, much of which must have been the result of immigration.

Keywords: Feral goats; control; density; immigration.

Introduction

The New Zealand Department of Conservation has controlled feral goats *(Capra hircus* L.) in about 160 areas totalling about 1 million hectares since 1990 (Parkes, 1993a). Eradication (the permanent removal of all goats) is presently judged by the Department's managers to be possible in only 39 of these areas. In the other areas goat populations must be reduced to low densities and a regular (generally annual) harvest of recruits and immigrants must be sustained to protect the flora and fauna affected by goats.

Managers need to understand how impacts on conservation values change as goat densities change so that they can judge how intensely and frequently maintenance control should be applied (Parkes, 1993b). However, impacts on resources are often complex and unlikely to be linearly related to pest densities (e.g., see the ungulate-forest understorey models proposed by Nugent and Fraser, 1993). The resources affected by goats may be independently affected by other agents of change, and simple models of rates of increase of harvested goat populations may be confounded by unknown levels of immigration. This makes direct measures of impact difficult to interpret and expensive to collect for every control operation.

Conservation managers could therefore benefit from a robust and cheap method of estimating goat densities that can be used to adjust ongoing control efforts.

One partial alternative to direct measures of impact is to measure indices of goat density that can be collected during routine control operations. Most goat control involves ground-based shooting by employees of the Department of Conservation (Parkes, 1990). Hunters are expected to report how much hunting effort they expend, how many goats they kill, and (less often) how many goats they see but do not kill. Logically, kill-rates should decrease as the population size decreases (e.g., Batcheler and Logan, 1963), and are therefore used to measure population trends. However, the linearity and precision of kill and encounter-rates have not been calibrated against absolute goat density.

This paper reports how three density indices changed as a population of feral goats was rapidly reduced by hunting through a wide range of densities to near-extinction. It also reports the costs and effort to achieve near-extinction, and the subsequent recovery of the population.

Study area and methods

The study was carried out in Dinner Creek (638 ha), a headwater catchment of the Waima (Ure) River in Marlborough. About 131 ha of the study catchment, mostly riparian areas, is forested with red beech *(Nothofagus fusca* (Hook. f.) Oersted), silver beech *(N. menziesii* (Hook. f.) Oersted), and kanuka *(Kunzea ericoides* (A. Rich) J. Thompson), or with dense scrub regenerating after previous fires and dominated by manuka *(Leptospermum scoparium* Forst. et Forst. f.) and matagouri *(Discaria toumatou* Raoul). The remaining 507 ha is grassland with mixed introduced and native species. Feral goats also inhabit the surrounding land (see

Brennan (1992) for a more detailed description of the study area).

Goats were counted, their age and sex noted, and their position mapped from two high observation points with a view of most of the grassland surrounding the forest patch. Scans of the study area, each lasting 15 min, were done before hunting (between 21 April and 11 May 1992; n = 94 scans), and on each of 11 days during the hunting campaign (13 - 19 May and 3 - 9 June 1992; n = 256 scans).

Hunting on the first day attempted to mimic the normal annual culling regime for the area, i.e., one hunter using a .222 calibre rifle and a dog attempted to 'cover the whole area. Subsequent hunting in May and June was an attempt to kill all the goats in the area. Two hunters were used (only one with a dog), and the hunting strategy and tactics varied each day depending on the weather. Sometimes the hunters worked together, and other times independently, with the hunter and dog concentrating on goats in the forest. There was no communication between the observer scanning the area and the hunters. The hunters recorded the number of goats seen, shot, or "escaped" (goats within rifle range that were missed or escaped while others in a group were being shot). They also recorded the age (adult or kid) and sex of the goats seen, and noted the time each day they spent hunting in forest or grassland. From these data kill and encounter-rates per hour were calculated.

The absolute number of goats present in each habitat type (forest or grassland) was estimated by comparing the cumulative number of animals shot in that habitat with the kill-rate index of density (Zippen, 1958). All goats shot can be pooled for this calculation if the probability of being seen or shot does not differ with age and sex of goats, and if the kill-rate is similar in forest and grassland. If the sex and age differences were important, we would expect the age structure and sex ratios of goats to change as the eradication campaign proceeded. We compared the ages and sexes of goats shot during the early half of the hunts (May) with those shot during the later half (June) and the number of adult goats of each sex that were seen by the hunters but escaped during both hunting periods (X^2 tests). We excluded data from 3 days when the hunters worked as a team, and for 1 day when hunting was curtailed by bad weather after only 20 min.

The density of goats estimated to be left at the start of each hunting day was calculated by subtracting the cumulative kill from the estimated total population and then comparing it with each of the three density indices for that day. A log transformation of the kill rates gave no consistent improvement in the regressions obtained. Linear models explained more of the variance than semi-log models.

To assess population recovery, the number of goats shot and the hunting effort was recorded in two short hunts in April and July 1993.

Results

Age, sex, and habitat biases

No significant differences were detected between the age structures or adult sex ratios of the May and June samples ($X^2 = 0.62$, $P = 0.39$; $X^2 = 0.24$, $P = 0.78$, respectively; Table 1). Pooling the samples by age and sex was therefore justified.

We treated each habitat separately to calculate population sizes from the kill-rate versus cumulative kill regressions because when the data were pooled the intercept on the x-axis was less than the number of goats shot. We did this despite the fact that there were no significant differences between the slopes of the regression (F = 1.53, $P = 0.25$) (Fig. 1), or between the mean kill-rates over the whole operation (1.1 goats hr^{-1} in the forest and 0.9 goats hr^{-1} in the grassland).

Absolute population size

A total of 65 and 35 goats were shot from the grasslands and forest, respectively, and as two goats were seen by the observer on the last hunting day but were not shot, the minimum known population size was 65 + 35 + 2 = 102.

Plotting the hourly kill-rates each day against the cumulative number of goats shot gave an estimated initial population size of 36 for the forest and 72 for the grassland (Fig. 1), i.e., where the regression line intersects the x axis. The estimated initial population size was therefore 108 goats (16.9 km^{-2}).

Relationships between density and indices of density.

The indices used were less reliable in grassland habitat (mean scan counts, kill-rates, and encounter-

Table 1: *Number of goats of each sex and age shot during two hunting periods, Dinner Creek. The relevant combinations are used in the X^2 tests.*

Hunting period	Number of adult males	Number of adult females	Number of Kids
May 1992	23	36	20
June 1992	6	12	3

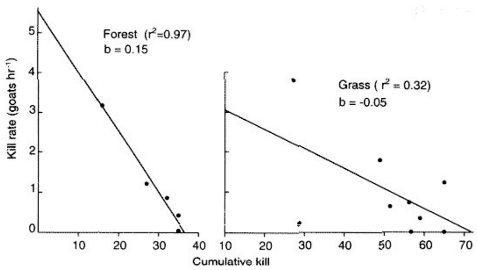

Figure 1: *Number of goats killed per hour on each day hunted against the cumulative number killed in forest (left) and grassland (right) habitats. Dinner Creek.*

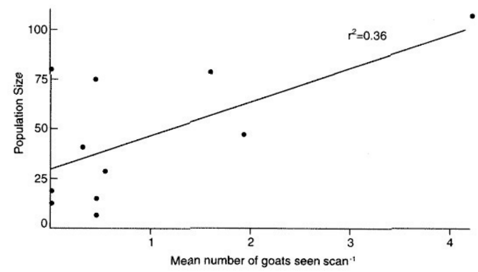

Figure 2: *Daily mean number of goats seen in the grasslands from two observation points (means of* 15 *min scans) at different overall population sizes.*

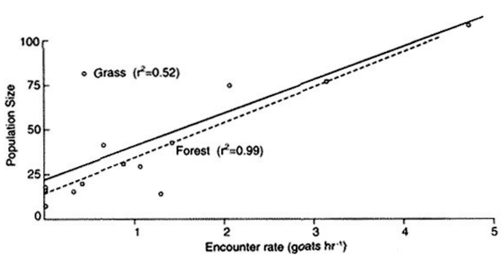

Figure 3: *Daily encounter-rates of goats by hunters in forest* (o) *and grassland* ([]) *habitats at different overall population sizes.*

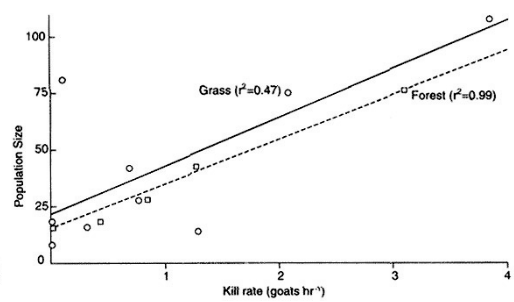

Figure 4: *Daily kill-rates of goats in forest* (o) *and grassland* ([]) *habitats at different overall population sizes.*

rates) than in the forest habitat (kill and encounter-rates) (Figs. 2 - 4). Kill-rate in the forest was the best index, explaining 99% of the variance, and the least useful index was obtained from the scans in grassland from the two fixed observation points, which explained only 36% of the variation.

Cost and effort to eradicate goats

A total of 104.75 hunter-hours were expended to kill 93 - 98% of the population present in the study area. A hunter in Nelson/Marlborough Conservancy costs about $50 per active hour hunting, including wages, allowances, travel, and overheads (M. Hawes, *pers. comm.).*

Therefore, it cost about $8.20 ha^{-1} to remove most of the goats in Dinner Creek, at a cost of $52 per goat. Eradication was not achieved, nor was it realistic as no attempt was made to eradicate adjacent goat populations, so that recolonisation was certain. The area was re-hunted in April 1993 for 21 hr (2 hunters over 2 days), and in July 1993 for 26 hr (2 hunters over 3 days), when 19 and 14 goats were killed, respectively (M. Brennan, *unpubl. data).* The average kill-rates of 0.91 and 0.54 goats hr^{-1} suggest the population had recovered from an estimated eight goats left after the hunting in June 1992 to about 35 goats before the April 1993 cull and about 30 goats before the July 1993 cull (Fig. 4). Assuming the eight goats surviving the 1992 culls had the same sex and age structure as the 1992 sample of shot goats (i.e., three males, four adult females, one female kid), and all females subsequently produced seven kids, Le., they bred at the rate observed among feral goat populations further south in Marlborough (1.42 kids female^{-1} yr^{-1}; Parkes, 1993a), then 15 of the goats present in April 1993 would have been survivors or their offspring, and 20 goats (57%) would have been immigrants.

Discussion

Kill-rates are routinely recorded in the annual reports of all the Department of Conservation's operations to control feral goats, and are used to estimate trends in population size as a measure of success of the control operations. Comparisons between kill-rates between areas or over several years in one area are valid only when similar hunting methods are used during similar conditions over similar habitats. Annual trends in kill-rates in individual operational areas should be valid providing a similar number of days are hunted each year.

The Dinner Creek trial suggests kill-rate and encounter-rate act as remarkably linear direct indices of goat density, at least during a single short control operation when immigration and births and deaths can be assumed to be zero, and over the range of densities from near zero up to about 17 animals km^{-2}. Scan-counts of goats in the grassland made from fixed observation points by an observer independent of the hunters gave the most variable (and least useful) results.

The goat densities in the study area are similar to those in many forested habitats, e.g., in the Raukumara Range (10 km^{-2}), in Mt Egmont National Park (10 km^{-2}), north Great Barrier Island (30 km^{-2}), but much lower than is possible in grasslands, e.g., Raoul Island (100 km^{-2}) and Macauley Island (1000 km^{-2}) (Parkes, 1993a). At higher goat densities when group sizes are likely to be larger, a higher proportion escape each encounter with a hunter (Parkes, 1984). Therefore, at some density above 17 km^{-2} the relationship between kill-rate and density is likely to reach a plateau.

Hunting effort has been measured in a variety of ways in past goat control operations, usually as hunter-days (a day on which a hunter did any hunting). Using this measure for the trial reported here, 35 hunter-days effort were expended. This intensity of hunting (18 ha per hunter-day) is much higher than the usual intensity of hunting in Nelson/ Marlborough (466 ha per hunter-day; *unpublished Department of Conservation data)*. However, the high immigration rates assumed from the rapid recovery of the Dinner Creek population reinforce the need either for frequent maintenance control or for large buffer zones if low densities of goats are to be maintained in the core areas.

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