The potential of poisoned foliage as bait for controlling feral goats (*Capra hircus*)

SCIENCE FOR CONSERVATION 204

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Published by
Department of Conservation
P.O. Box 10-420
Wellington, New Zealand

Science for Conservation is a scientific monograph series presenting research funded by New Zealand Department of Conservation (DOC). Manuscripts are internally and externally peer-reviewed; resulting publications are considered part of the formal international scientific literature.
Titles are listed in the DOC Science Publishing catalogue on the departmental website http://www.doc.govt.nz and printed copies can be purchased from science.publications@doc.govt.nz

ISSN 1173–2946
ISBN 0–478–22288–2

This report was prepared for publication by DOC Science Publishing, Science & Research Unit; editing by Lynette Clelland and layout by Ruth Munro. Publication was approved by the Manager, Science & Research Unit, Science Technology and Information Services, Department of Conservation, Wellington.

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ABSTRACT

An operational-scale trial to control feral goats using poisoned foliage was conducted in the 6380-ha Mangaotane catchment of the Raukumara Ranges, North Island, New Zealand, in 1986. An estimated 87% of the goats were killed. Results from this trial (effort, costs, and efficacy) are compared with those from other trials using poisoned foliage aimed at goats and deer, and also compared with other control methods such as various forms of hunting and aerial baiting. The control methods are then discussed in terms of their suitability for dealing with particular management scenarios and, particularly, for remnant goat populations during attempts at eradication. Poisoned foliage may be useful for high-density goat populations that are in physical refuges that cannot be hunted from the ground or the air. It is noted that 1080 in gel is not registered for feral goat control in New Zealand.

Keywords: Feral goat, control, poisoned foliage, compound 1080, eradication.

Veltman, C.J.; Parkes, J. 2002: The potential of poisoned foliage as bait for controlling feral goats (*Capra hircus*). *Science for Conservation 204*. 21 p.

1. Introduction

The New Zealand Department of Conservation (DOC) controls feral goats (*Capra hircus*) in many operations over about 1.5 million ha at an annual cost of about $5.8 million. Most of this control is conducted by ground hunters, (usually with dogs) and, less commonly, by hunters shooting from helicopters. However, there are some situations where these traditional techniques are difficult to apply, and more specialised control methods are needed. One of these methods is to use 1080 in a gel or paste smeared on the leaves of palatable plants, which are then used to poison the goats. Trials of the method were conducted in the 1980s but only one of the two studies on goats was published (Parkes 1983). In this report we summarise the results of both goat control trials conducted in the 1980s in the Raukumara Ranges in order to compare the efficacy of this method with others. We discuss the strategic applications of goat control methods including use of poisoned foliage, even though this method is not presently registered for goat control.

2. Background

From 1956 to 1986 the New Zealand Forest Service experimented with poisoning goats, red deer (*Cervus elaphus*), white-tail deer (*Odocoileus virginianus*), Bennett's wallaby (*Macropus r. rufogriseus*) and tammar wallaby (*Macropus eugenii*, called dama wallaby in New Zealand) using sodium monofluoroacetate (Compound 1080) mixed into a carrier material and smeared on the leaves of palatable plants that were then tied down or broken within reach of the pests to act as baits (Table 1). Two further poisoning trials were conducted for the Animal Health Board (Sweetapple 1995, 1997) and when foliage was cut and baited with 10% 1080 on Auckland Island in 1990, two goats were known to have been killed (P. Willemse, pers. comm.).

Research was also carried out to develop carriers for the toxin that would have variable bait life whilst remaining palatable to the target animals. For example, carrier substances that caused leaves to die or fall from twigs could be used for short-life baits so that areas would not have to be closed to the public for extensive periods. Alternatively, waterproof substances could be used for long-life baits to ensure all target animals in a block had time to encounter baits (Batcheler & Challies 1988; Parkes 1991).

Although the early poisoning trials were mostly successful, the method has not been used operationally since the failed attempt to eradicate deer from Secretary Island in 1975. In that operation, many (but not all) deer were killed (Tustin 1977; Nugent et al. 2001) but, because immigration from neighbouring mainland herds could not be prevented, the aim of eradication was never achievable. There are several reasons why the method has not been used operationally. First, it may not be more efficient (i.e. achieve a similar reduction

in pest numbers at a reduced cost/ha, or a greater reduction at the same cost/ha) over large areas than traditional control methods such as hunting, at least for feral goats (Parkes 1983). Second, the method is highly unpopular with hunters, particularly when it targets deer (e.g. see the letters to the editors in hunting magazines in New Zealand). Third, the carbopol-1080 mix is only registered for use against wallabies and deer. If other pests like goats are to be controlled using this combination of carrier and toxin, the operations must be conducted under experimental use permits. Fourth, the use of toxins poses some risk to non-target animals, although Morgan (1999) showed that only a few species would eat gel baits developed for possums (composition unstated but containing sugars, lures and Bitrex® as a repellent). No up-to-date information is available on the humaneness of 1080 for feral goat control.

Despite these drawbacks, poisoned foliage may have some modern use as a specialist technique to deal with high-priority problem animals that cannot be killed by other means. An example is when pests persist in an area, even after many years of conventional control, because they have found a physical or behavioural refuge from hunting (D. Forsyth, pers. comm.), they might be put at risk by foliage poisoning. The Animal Health Board has also been interested in testing whether the method might kill tuberculous wild deer living at very low densities in dense forest habitats (Sweetapple 1997).

In this report, we compare the effort required and kill rates achieved using foliage poisoning with other control methods, and recommend where and when it might be considered for pest control in New Zealand, with an emphasis on the eradication of feral goats.

TABLE 1. PREVIOUS TRIALS USING 1080 ON FOLIAGE TO POISON PEST ANIMALS.

YEAR	TARGET SPECIES	AREA	TOXIN CARRIER	REFERENCE
1956	Red deer, goats	Haurangi Range	Water	Pracy (1956)
1969	Red deer	Pohangina	Adhesive+wetting agent	Barnett et al. (1970)
1970	Bennett's wallaby	S. Canterbury	Adhesive+wetting agent	Tustin (1971)
1975	Red deer	Secretary Island	Carbopol gel	Tustin (1977)
1981	White-tail deer	Stewart Island	Carbopol gel	Nugent (1990)
1982	Feral goats	Mangakirikiri	Carbopol gel	Parkes (1983)
1983	Bennett's wallaby	S. Canterbury	Carbopol gel	Warburton (1990)
1986	Feral goats	Mangaotane	Carbopol and petrolatum	This report
1988	Dama wallaby	Okataina	Carbopol gel	Warburton (1990)
1990	Goats	Auckland Is.	Carbopol gel	P. Willemse (pers. comm.)
1995	Red deer	Hauhungaroa	Carbopol/petrolatum mix[1]	Sweetapple (1995)
1997	Red deer	Hauhungaroa	Petrolatum	Sweetapple (1997)

[1] The 1080 in this trial was only 1% as compared with 10% in all others since 1975.

3. Objectives

- To report the results of an operation by the Forest Service in 1986 using poisoned foliage for control of feral goats in Mangaotane catchment and compare them with published results of an operation done in 1982.
- To compare the costs and effectiveness of the poisoned foliage method with other control methods for reducing goat numbers.
- To discuss the utility of the poisoned foliage method and other control methods in eradication campaigns.

4. Methods

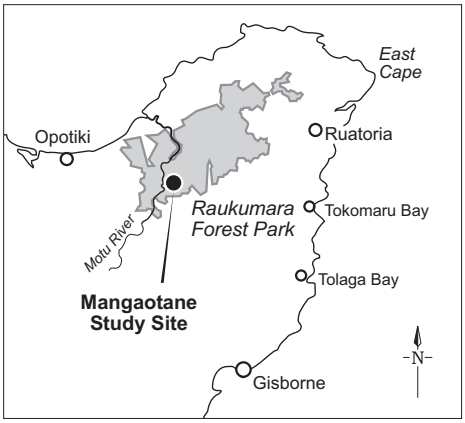
4.1 THE MANGAOTANE TRIAL

The 6380-ha Mangaotane study site is located in the south-western part of the Raukumara Forest Park on the true-right bank of the Motu River (Fig. 1). The forests in the area are dominated by tawa (*Beilschmiedia tawa*) and kamahi (*Weinmannia racemosa*), with significant amounts of tawari (*Ixerba brexioides*) and red beech (*Nothofagus fusca*) on the ridges, and mahoe (*Melicytis ramiflorus*) and wineberry (*Aristotelia serrata*) on seral slip sites. The lower terraces are dominated by podocarps. The poison trial was part of a larger effort made by the Forest Service to eliminate newly-established goat herds on the west side of the Motu River and to stop them spreading into the goat-free areas in the Te Kahika catchment.

The study area was divided into seven contiguous blocks ranging from 640 to 1300 ha, in which about 75% of each block was considered to be habitat favoured by goats. One or two pairs of people worked in each block, concentrating on the areas favoured by goats. From 14 January 1986 to 23 January 1986 they smeared about 0.25 g of 1080 gel on each of about 20 leaves (depending on the branch size) on branches of palatable plants that were broken or tied down to browse level. One branch with poisoned leaves constituted a 'bait'. Mahoe, wineberry, tawari, pate (*Schefflera digitata*), *Coprosma lucida*, *Coprosma australis*, and broadleaf (*Griselinia littoralis*) were the most commonly baited species, as all were known to be favoured by goats in diet studies in other areas (Rudge 1990), and they had leaves large enough for application of the gel. Each day, the number of baits laid, the time spent doing it, and the number of live goats seen were recorded.

The toxin used was sodium monofluoroacetate (1080) in Carbopol 941 (a carboxyvinyl polymer) gel with a toxic loading of 10% 1080. One litre of the registered mixture (Agricultural Chemicals Board Registration No. 2345) consists of 100 g of 1080, 50 g of carbopol, and 0.3 g of lissamine V200 green dye all dissolved in 760 ml of water and buffered to pH 8.5 with 90 g of triethanolamine. The gel was smeared onto the leaves directly from the plastic tubes. An unknown but small number of tubes of petrolatum grease (rather than

Figure 1. Mangaotane study site.



carbopol gel) with 10% 1080 were inadvertently used, but we do not believe this would have affected goat mortality rates.

The study area had been hunted by ground hunters with dogs on six occasions between 1979 and 1986, providing an index of pre-operational goat abundance. Between 19 March and 4 May 1986, immediately after the poison operation, it was hunted again and then annually between 1990 and 1995. We have used the kill-rates achieved by hunters as an index of goat densities (Brennan et al. 1993). We measured the success of the poisoned foliage trial as the difference between average annual kill rates before and after the operation.

4.2 OTHER INFORMATION

The poisoned foliage method was tested on feral goats in a 1200-ha block in the Mangakirikiri catchment on the true-left bank of the Motu River in the Raukumara Ranges in 1982 (Parkes 1983). This area had similar forests to those in the Mangaotane, but the goats had been present for many decades longer. Similar plant species to those in the Mangaotane trial were baited, but an attempt was made to achieve an even coverage of baits across the treated area, rather than concentrating on patches clearly favoured by goats.

The cost and effectiveness of other goat control techniques (see section 5.4) have been gleaned from published material and from unpublished data held by Landcare Research and DOC. All dollars have been transformed into 2000 values.

5. Results

5.1 THE MANGAOTANE TRIAL

The operation required 1234 worker-hours (140 worker-days) to set 4380 poison baits over 6380 ha, i.e. at an average density of 0.69 baits/ha or about 1 bait/ha over the areas of preferred goat habitat (Table 2).

We estimate that about 87% of the goats were killed in the poison trial. This is based on the decline in kill-rate between the average number shot over the six pre-poisoning hunting operations (3387 goats in 1614 hunter-days) and the rate in the 1986 post-poison operation (58 goats in 220 hunter-days) (Fig. 2). Ground hunting recommenced on an annual basis in 1990, and kill-rates were higher than those immediately after the poisoning operation (Fig. 2).

TABLE 2. NUMBER OF BAITS LAID AND THE TIME NEEDED TO DO SO IN SEVEN BLOCKS IN THE MANGAOTANE AREA, AND AN ESTIMATE OF THE RELATIVE DENSITY OF GOATS IN EACH BLOCK.

BLOCK	AREA (ha)	BAITS LAID	WORKER HOURS	GOATS SEEN/HOUR
Motu Gorge	1130	786	215	0.214
Grass	840	204	44	0.022
Troys	640	979	280	0.189
Green Hut	1220	933	301	0.176
Green Hut heads	830	843	253	0.300
Lawns	690	324	80	0.313
Arowhenua	1030	311	61	0.197
Totals	6380	4380	1234	0.216

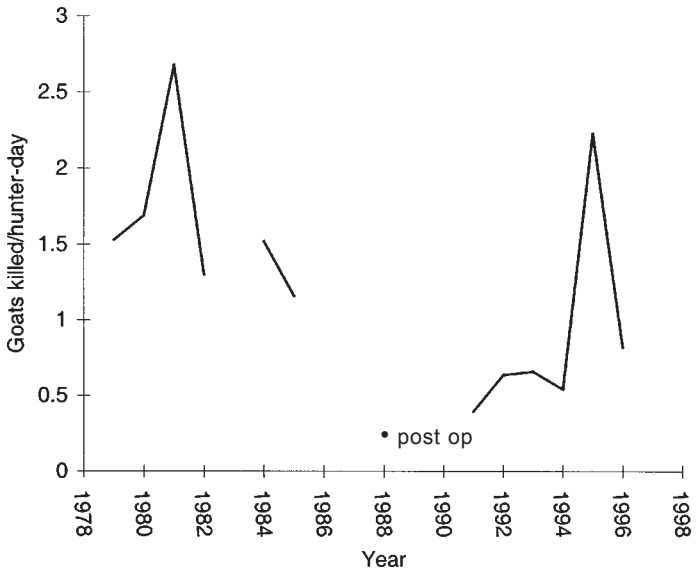


Figure 2. Goats killed per hunter-day in the Mangaotane catchment, 1979–96, and post-operational value.

5.2 COMPARISON WITH THE MANGAKIRIKIRI TRIAL

Nearly 3000 baits were laid in 1200 ha (about 2.5 baits/ha) at Mangakirikiri, taking 56 worker-days. The proportion of goats poisoned was estimated from changes in faecal pellet densities and suggested that a kill of 97% was achieved. The number of goats seen per hour before poisoning began was 0.77 and declined to 0.04 goats/hour after poisoning, a reduction of 94% (Parkes 1983).

5.3 COMPARISON WITH FOLIAGE-POISONING TRIALS ON OTHER UNGULATE SPECIES

The use of poisoned foliage against whitetail deer and red deer in New Zealand has generally been successful (Table 3). The only clear failure among these trials was when the toxic load in the baits was reduced from 10% to 1% in the first Hauhungaroa trial (Tables 1 and 3).

On average, for the three successful trials against ungulates where effort was recorded, it took 0.3 ± 0.1 hours/ha to lay the baits for an average kill of 85% (Table 3). The reduced effort and lower density of baits achieved at Mangaotane by targeting areas favoured by goats did not appear to jeopardise operational effectiveness.

5.4 COMPARISON WITH OTHER GOAT CONTROL METHODS

5.4.1 Ground hunting: (a) individual hunters using dogs

The traditional method for controlling goats is for each hunter to be allocated a hunting block. This is partly justified on safety grounds, but is partly an inheritance from older regimes when hunters were paid a bonus for each animal they shot (deer in those days) and 'competition' from other hunters was discouraged.

TABLE 3. SUMMARY OF THE EFFORT AND EFFECTIVENESS OF FOLIAGE BAIT POISONING TRIALS.

OPERATION	AREA (ha) TREATED	BAITS/ha	WORKER HOURS	EFFORT (h/ha)	% KILL	REFERENCE
Stewart I. Whitetail deer	160	2.5	No data	No data	80%+	Nugent (1990)
Stewart I. Whitetail deer	200	5	No data	No data	100%	Nugent (1990)
Hauhungaroa Red deer[1]	400	2	71	0.778	0%	Sweetapple (1995)
Hauhungaroa Red deer	350	2	114	0.326	79%	Sweetapple (1997)
Mangakirikiri Feral goats	1200	2.5	c. 450	0.375	90%+	Parkes (1983)
Mangaotane Feral goats	6380	0.686	1234	0.193	87%	This report

[1] Toxic loading 1%.

The efficacy of hunters using dogs needs to be analysed for three different situations. First, there are cases when a single, short-term one-hit operation has eradicated a goat population. Second, hunters with dogs carry out the short-term initial 'knockdown' phase of new sustained control operations. Third, hunters with dogs carry out routine maintenance control annually once the initial goat population has been reduced to some acceptable density (Table 4, Fig. 3). We have selected examples where hunting with dogs was the only control method used and operations where the same area was consistently hunted between years.

On average, eradication done in a one-hit operation took 0.963 ± 0.318 (SE) hours/ha, initial knockdowns took 0.511 ± 0.109 hours/ha, and the ongoing maintenance control averaged 0.172 ± 0.059 hours/ha/year. We have restricted the eradication examples to operations conducted over a limited period (3 years or less) and where at least 50 goats were killed (163 at Pohueroro and 67 at Bream Head). Many other successful eradication operations (Parkes 1990, 1994) took much longer or involved only a few goats.

The points of interest from these results are that (a) getting the last few percent of a herd takes as much effort as the initial knockdown, and (b) foliage poisoning requires less effort to achieve the initial reduction than does hunting. An unanswered question (because no trial has yet tested it) is whether foliage poisoning alone, or when used after an initial reduction by hunters, could achieve eradication.

TABLE 4. EFFICACY OF GROUND HUNTING GOAT CONTROL OPERATIONS. SITES SHOWN ON FIG. 3.

OPERATION	AREA (ha)	HOURS OF WORK	INTENSITY h/ha/y	ESTIMATED REDUCTION IN GOAT NUMBERS (%)	TOTAL GOATS KILLED	REFERENCE
One-hit eradication attempts:						
Pohueroro (1990–91)	1000	1280	1.28	100%	163	J. Parkes (unpubl. data)
Bream Head (1990–92)	1000	645	0.645	100%	67	J. Parkes (unpubl. data)
Initial knockdowns in sustained control:						
Dinner Creek	638	105	0.165	93–98%	108	Brennan et al. (1993)
N. Whareorino (1996/97)	8360	6032	0.721	70%+	3352	Fraser & Montague (1999)
Moeatoa (1995/96)	9000	4488	0.499	63%+	3895	Fraser & Montague (1999)
Mangakirikiri (no dogs)	1200	488	0.407	95%	112	Parkes (1983)
Te Paparahi (1986)	3900	2976	0.763	94%	804	J. Parkes (unpubl. data)
Maintenance control (Yearly averages):						
Mt Egmont (1990–98)	30000	2572	0.086	c. 5.6%	881	Stronge & Dijkgraaf (2001)
Karioi (1991–1999)	1700	623	0.366	c. 9.6%	83	J. Parkes (unpubl. data)
Moehau 1990–2000)	8000	1058	0.132	0%	123	J. Parkes (unpubl. data)
Whitecliffs (1991–99)	2600	272	0.105	0%	105	Stronge & Dijkgraaf (2001)
Taramoukou (1995–1999)	700	120	0.171	+40%	152	Stronge & Dijkgraaf (2001)

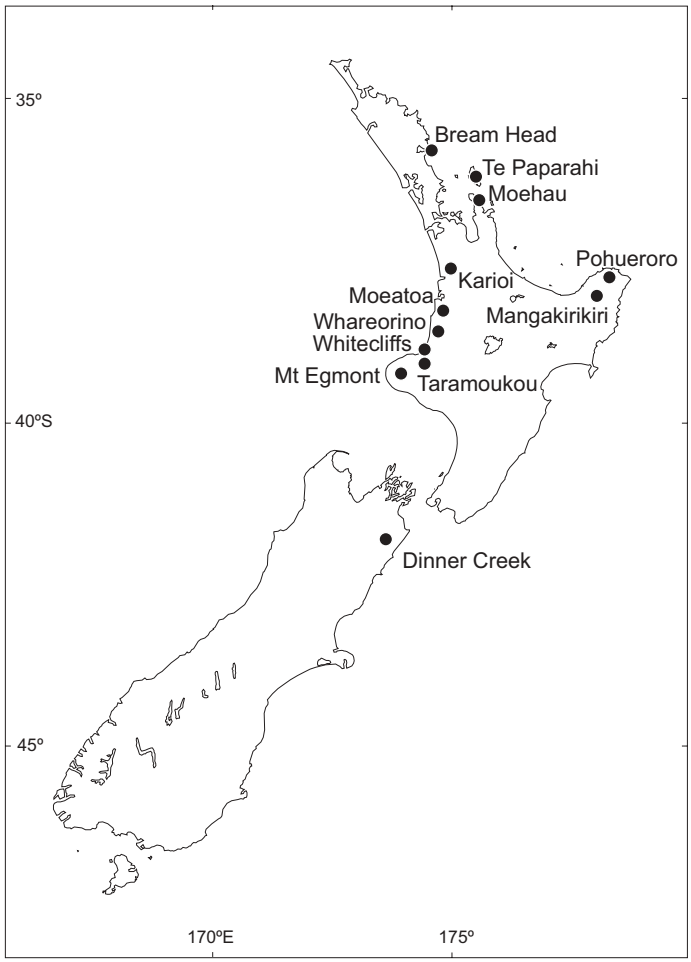


Figure 3. Locations of ground hunting operations listed in Table 4.

5.4.2 Ground hunting: (b) team hunting with dogs

Cooperative hunting by teams of hunters has been tried at various times since ungulate control began in the late 1930s (e.g. Batcheler & Logan 1963), but apart from anecdotes in the numerous autobiographies of the hunters, the results were never reported. The advent of good short-range VHF radios which allowed hunters to maintain continuous contact, and better trained dogs has led to the technique being used successfully against feral goats.

Many goats escape an encounter with a single hunter and dogs (Parkes 1984) and become exceedingly wary. The team hunting system attempts to overcome this and to kill all goats at the first encounter. The system operates by having hunters in a line across the area to be hunted each day who try to work to natural boundaries such as rivers. They keep about 100–150 m apart in forested habitats and rely on their dogs (usually only one or two per hunter) to stop any goats getting back through the line of march. The dogs are trained to chase and bail any goats encountered, which are despatched by the nearest hunter. Only those dogs making the initial contact bail the goats, and once the nearest hunter kills the goats the dogs return to their handlers. The whole drive is coordinated by continuous contact between the hunters. Where eradication is the aim, the hunters might make several sweeps over the same area until no more goats are seen or killed (Parkes et al. in press).

We have only a few operations where the results of this method have been reported. In one case, on Lord Howe Island, the operation aimed to eradicate goats. In another, at Taurewa, operations were conducted about 12 months apart to reduce goats to near zero density (Table 5). During the first sweep at Taurewa, 87% of goats were killed in 90 hunter days over 1500 ha (C. Speedy, pers. comm.), providing an estimate of effort required for knockdown. The average hunting intensity, combining both sites, was 1.421 ± 0.499 hours/ha.

TABLE 5. EFFICACY OF TEAM HUNTING.

OPERATION (NO. OF SWEEPS)	AREA (ha)	EFFORT (h)	INTENSITY (h/ha/y)	REDUCTION IN GOAT NUMBERS (%)	NO. GOATS KILLED	REFERENCE
Lord Howe I. (3–11)	700	1344	1.92	99%	106[1]	Parkes et al. (in press)
Taurewa (2)	1510	1392	0.922	100%	130	Fraser & Montague (1999)

[1] Plus 189 killed from helicopters before the ground hunting began.

5.4.3 Aerial hunting

Shooting goats from a helicopter costs between about $420 and $1100 per hour, depending on the type of helicopter used. Kill-rates can be very high in non-forested habitats with high goat densities, but averaged about 30 goats/flying-hour in operations in Marlborough and Central Otago in the early 1990s (Parkes 1994). We do not know what sized areas were covered in these operations and what percent of the populations was killed.

In forested habitats in the North Island, aerial hunting has been used in conjunction with ground hunting in a few places. In central Coromandel (14 450 ha), 26 flying hours were spent hunting in five years between 1993 and 1999 to kill 413 goats. Over the same period, 2064 goats were killed by ground hunters and their kill-rate dropped by 40%.

In the southern Whareorino area (8360 ha), 35 flying hours were spent hunting goats over three years between 1998 and 2000 to kill 835 goats. Ground hunters killed 4342 goats over the same period and their kill-rate dropped by 42%.

Working over rugged, forested terrain near Armidale in New South Wales, an experienced helicopter pilot and on-board hunter killed 40% of a naïve population of feral goats, which rose to 59% when they worked in conjunction with spotters on the ground (Bayne et al. 2000).

5.4.4 Hunting using Judas goats

The Department of Conservation has been using radio-collared goats (Judas goats) to locate and kill any animals associated with the Judas animals.

Eleven goats were released and tracked in the upper Shotover and Polnoon catchments near Mount Aspiring National Park between December 1991 and August 1992, and 143 goats associated with them were shot (Hondelink 1993). The programme was extended to include the Maungatua and Taieri River reserves in coastal Otago. From 1990 to 1998 a total of 94 Judas goats were used

in the Mount Aspiring National Park/Shotover area, and 19 in the coastal Otago reserves (Thomas & Mudford 1998a). Goat densities were at least about 0.5 animals/ha in the late 1980s as measured by the known kills from aerial campaigns in small (1000–2000 ha) subcatchments, and had been reduced to below 0.008 animals/ha by 1995 during the Judas goat operation (Thomas & Mudford 1988b). No estimates of the hunting effort were available from the Otago operations, but hunting effort data are now routinely collected as part of the Judas operations.

5.4.5 Aerial 1080 poisoning

Aerial sowing of toxic baits to control possums (*Trichosurus vulpecula*) often results in the deaths of some non-target pests, including fallow deer (*Dama dama*, Daniels 1966), thar (*Hemitragus jemlahicus*, Douglas 1967), feral sheep (*Ovis aries*, Parkes 1989) and pigs (*Sus scrofa*, Parkes 1989). However, the proportion of ungulate populations killed by toxic baits sown from the air has been highly variable, and generally very low for feral goats (Table 6).

Some research into bait take by rodents provided an opportunity to sample goats living in the same area for evidence of bait consumption. Pelleted cereal baits (non-toxic Wanganui No. 7) impregnated with rhodamine dye were aerially distributed at 2–3 kg/ha over 180 ha of forest in the Mangaio catchment of Whanganui National Park on 17 October 2000. Over the next 5 days 20 goats (8 adult males, 9 adult females, 3 kids) were shot in the drop zone and no dye was found in their stomachs, guts, muscle tissue, or around their faces or mouths (N. Marsh, pers. comm.).

TABLE 6. PROPORTION OF UNGULATE POPULATIONS KILLED BY AERIALLY SOWN TOXIC BAITS. SITES SHOWN ON FIG. 4.

SPECIES	TRIAL AREA	YEAR	BAIT TYPE, TOXIC LOAD AND SOWING RATE	PRE-FED WITH NON-TOXIC BAIT?	% KILLED	REFERENCE
Red deer	N. Pureora	1996	Carrot (0.09% at 15 kg/ha)	Yes	57	Sweetapple & Fraser (1997)
Red deer	N. Pureora	1988	Cereal (0.08% at 10 kg/ha)	Yes	43	Fraser (1989)
Red deer	Pureora	1994	Carrot (0.15% at 15 kg/ha)	Yes	34	Fraser et al. (1995)
Red deer	Pureora	1994	Carrot (0.15% at 15 kg/ha)	No	42	Fraser et al. (1995)
Red deer	Titiraupenga	1997	Carrot (0.08% at 15 kg/ha)	Yes	93	Fraser & Sweetapple (2000)
Red deer	Titiraupenga	1997	Carrot (0.15% at 15 kg/ha)	Yes	92	Fraser & Sweetapple (2000)
Red deer	Wainuiomata	1999	Cereal (0.15% at 3 kg/ha)	Yes	5	Nugent et al. (2001)
Red deer	Orongorongo	1999	Cereal (0.15% at 3 kg/ha)	No	54	Nugent et al. (2001)
Red deer	Haurangi	1961	Carrot (0.08% at 12 kg/ha)	No	42	Parkes (1989)
Fallow deer	Caples	1956	Carrot	Yes	50	Daniels (1966)
Fallow deer	Blue Mtns	2001	Cereal (0.15% at 2 kg/ha)	yes	c. 70	Nugent & Yockney (2001)
Thar	Dobson	1964	Carrot (0.17%)	Yes	52	Douglas (1967)
Feral sheep	Haurangi	1961	Carrot (0.08% at 12 kg/ha)		63	Parkes (1989)
Feral pigs	Haurangi	1961	Carrot (0.08% at 12 kg/ha)		20	Parkes (1989)
Feral goats	Waiau Toa	1960	Carrot	Yes (×2)	0?	Parkes (1989)
Feral goats	Haurangi	1961	Carrot (0.08% at 12 kg/ha)		9	Parkes (1989)
Feral goats	Peggioh	1994	Cereal		25	Forsyth & Parkes (1995)

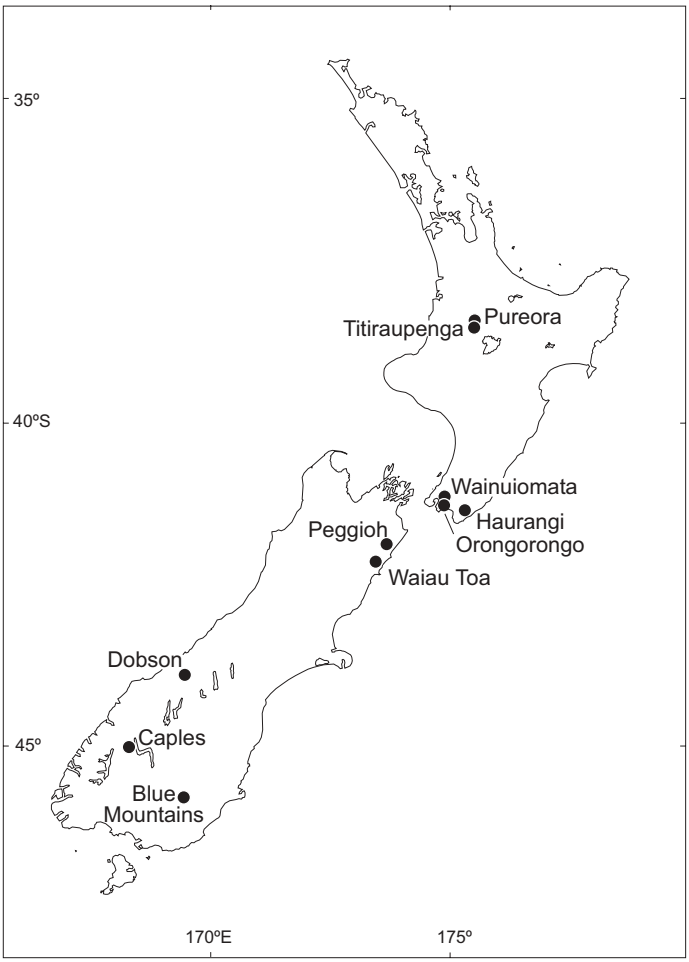


Figure 4. Locations of aerial 1080 operations listed in Table 6.

Forsyth & Parkes 1995 tried to improve the palatability of cereal bait to goats by adding ingredients like chopped broadleaf. However, when the non-toxic bait containing a marker chemical was aerially sown over 380ha inhabited by feral goats, only 6 out of 24 goats shot later in the area had eaten the baits (Forsyth & Parkes 1995).

The cost of aerially sowing baits (cereal baits at 2 kg/ha for possum control) over large areas is approximately $15/ha (D. Morgan, pers. comm.).

5.5 COMPARISON OF COSTS FOR DIFFERENT METHODS

It is not simple to compare the costs of different methods of goat control from operational data. This is because the methods are often applied at different temporal and spatial scales, in different habitats, against different densities of goats, have different support costs, and achieve different control success. However, some rough cost comparisons can be made for those methods where we can estimate effort in person-days per unit area, assuming the costs per person are constant between methods. We assume $30 per hour to include wages and overhead costs (Table 7).

TABLE 7. COMPARISON OF COSTS OF DIFFERENT GOAT CONTROL METHODS.

CONTROL METHOD	NUMBER OF CASES	EFFORT (h/ha)	COST ($/ha)	OPERATING COSTS ($/ha)[1]	TOTAL COST	EFFICACY (% KILL)
Foliage poisoning	3	0.42	10.00	0.50	$10.50	High
One-hit eradication by ground hunting	2	0.96	28.80		$28.80	High
Initial knockdown by ground hunting	5	0.51	15.33		$15.33	Variable
Maintenance control by ground hunting	5	0.17	5.16		$5.16	Low to medium
Team hunting for eradication	2	1.42	42.63		$42.63	High
Team hunting for knockdown	1	0.48	16.20		$16.20	High
Aerial shooting	0	No data				Variable
Aerial shooting with Judas goats	0	No data				Unknown
Aerial 1080 poisoning	3	No data		15.00	$15.00	Low

[1] Costs over and above labour and its normal overheads (e.g. special equipment, baits, toxins, helicopter hire, etc.).

5.6 COSTS PER GOAT VERSUS GOAT DENSITY—STRATEGIC AND TACTICAL IMPLICATIONS

It is often the case that the cost per pest removed increases as pest density declines. This increase can rise steeply for tactics such as hunting or trapping where managers can easily vary their effort (e.g. Parkes et al. (1996) for goats; Choquenot et al. (1996) for feral pigs; Cowan (1992) for possums). When the control method has a fixed cost per unit area regardless of pest density, such as aerial baiting at a set sowing rate or foliage baiting at a set bait density, costs rise as a simple function of the size of the treated area and the cost/animal removed increases more linearly (Fig. 5).

The strategic implications of these relationships are that:

- A control tactic that costs a lot per unit area and that would not be worth using at high pest densities might be worth using at low pest densities when the costs per animal killed are high anyway.
- If the aim is to eradicate the pest, control tactics may need to be changed or additional tactics brought in if the remnant pest population is in some form of refuge (see 5.7 below).
- A risky control tactic, i.e. one with generally adverse side effects or that is socially ill-favoured, might be acceptable if used over a short period or a small area to solve some intractable problem.

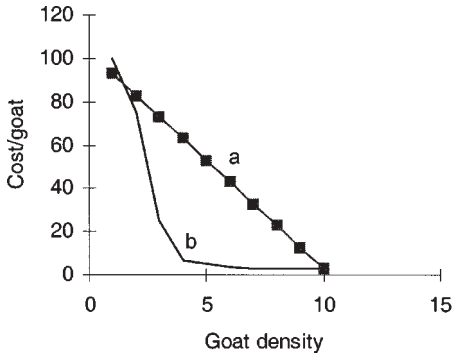


Figure 5. General relationships between the cost per animal killed and population density for (a) area-dependent and (b) effort-dependent control methods. The former is either completely or partially independent of the density of pests, e.g. the cost of aerial baiting might rise only slightly if more baits are required at very high pest densities. The latter rises exponentially as surviving animals become harder to put at risk.

5.7 THE NATURE OF REFUGIA AND HOW TO DEAL WITH THEM

Goats cannot be eradicated from a patch of forest unless immigration is zero, kill rates are greater than breeding rates of survivors, and all goats are put at risk (Parkes 1990).

The third condition cannot be satisfied if goats have found a refuge that allows them to escape from dogs and hunters. Such refuges might be caves, cliffs or patches of impenetrable vegetation. However, refugia are not always physical. If goats have learned to avoid hunters, or if they live in habitat that is not searched by hunters, or if they avoid consuming poison baits, they are effectively exploiting a behavioural refuge that makes it more difficult to eradicate them.

A recent analysis of goat harvests at Mt Egmont has uncovered the possibility that not all goats are at risk from hunters, probably because they can evade them by seeking refuge in dense vegetation where they are safe and/or that is avoided by hunters (D. Forsyth, pers. comm.). It also appears that some goats escaped hunters at Lord Howe Island during recent work to eradicate them (Parkes et al. in press), probably by hiding amongst rocks and in caves. Bayne et al. (2000) have described how goats that were previously exposed to helicopter hunting took evasive action and successfully avoided being killed, even when ground spotters were used to assist the helicopter hunter.

These cases reinforce the need to overcome the use of refuges by goats in order to achieve eradication. The question is how to do it.

One answer is to simply increase the control effort. However, this assumes that the 'refuge' is merely the fact that goats can replace their losses as fast as the hunters can kill them. If there is a real refuge where some goats are not at risk, managers may need to consider switching or adding new control methods to eradicate the survivors. The best way to put goats in refugia at risk depends on the circumstances, but we can speculate on possible uses of some of the specialist control techniques needed to achieve these goals (Table 8).

TABLE 8. NATURE OF REFUGIA FOR GOATS AND POTENTIAL CONTROL METHODS TO OVERCOME THEM WHERE ERADICATION IS THE AIM.

NATURE OF REFUGE	GOAT DENSITY	RECOMMENDED METHOD
Physical (goats visible, e.g. on bluffs)	All	Helicopter shooting
Physical (goats invisible, e.g. caves, thick vegetation)	High	Foliage poisoning
	Low	If goats come out, use Judas goats
		If goats do not come out, no recommendation
Behaviour of the goats (e.g. goats avoid the hunters)	Generally low	Team hunting with dogs
Behaviour of the hunters (e.g. hunters avoid some areas)	All	Improve training
		Develop incentives
		Systematic coverage
Behaviour of both goats and hunters (e.g. kill-rates are less than or equal to recruitment rates)	Generally low	Increase the current effort

6. Summary

The use of 1080 in a carbopol gel on palatable foliage at approximately 0.69 baits/ha reduced goat abundance by about 87% in an operation that was carried out in the Mangaotane catchment in the Raukumara Ranges in 1986. From this result, and two other trials in which ungulates were targeted, we estimate that the effort required to lay baits for an average kill of 85% is 0.3 ± 0.1 hours/ha.

The intensity of ground hunting in goat control operations ranged from 0.086 to 1.28 hours per hectare per year, compared with 0.922 to 1.92 hours per hectare per year when team hunters were used. We could not compare these values with aerial hunting effort or with effort expended on Judas goat hunting operations because information on effort was not available. Least effort might be expected from aerial 1080 poisoning, but bait uptake by goats is low.

A switch of control tactic may be necessary when goats have found refuge in a habitat that cannot be effectively hunted, or when goats have learned to avoid the hunters and/or helicopters. Foliage poisoning may be useful for high-density goat populations that are in physical refuges that cannot be hunted from the air or on the ground.

We note that 1080 in carbopol gel is not registered at present for goat control.

7. Acknowledgements

This report originated from work carried out under Department of Conservation Investigation no 3525. We thank Norm Marsh (Environment Canterbury, formerly DOC Wanganui Area) for unpublished data used in this report. Pete Willemse alerted us to the Auckland Island trial by Kingsley Timpson. Cam Speedy provided additional information about the Taurewa operation and David Forsyth gave us an unpublished manuscript about goats in refugia on Mt. Egmont. Chris Edkins prepared the maps. The report was improved by comments from Bruce Warburton, Cam Speedy, Bill Fleury, Alastair Fairweather and two anonymous referees. Unpublished reports cited here are available on request from J. Parkes.

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