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FERAL GOATS ON RAOUL ISLAND. I. EFFECT OF CONTROL METHODS ON THEIR DENSITY, DISTRIBUTION, AND PRODUCTIVITY

Summary: Goats were liberated on Raoul Island early in the 19th century. Attempts to eliminate the goats commenced in 1937 and have accounted for at least 15 000 animals. Since 1972, when annual hunting expeditions began, both the number of goats and the area over which they range have steadily declined and the herd is now almost extinct. Despite these changes, the mean group size of goats in 1981-83 remained the same at 3.19, 2.74 and 3.24 respectively. On average, 19% of goats escaped each encounter with the hunters. The breeding season extended from January-September, with most activity in April-June. Productivity of the herd has increased by 77% since 1972, presumably in response to an improving food supply. This increased productivity has been achieved by an increase in the frequency of breeding from an average of 0.83 times/year in 1972 to an average of 1.08 times/year since 1981, increases in breeding rates of young females, and in mean litter sizes of older females. These parameters, and the primary sex ratio of 49:34, are used to calculate an estimate of exponential birth rate of 0.529.

Keywords: Feral goats; Capra hircus; Bovidae; Raoul Island; control; density; distribution; group size; breeding season; breeding rates; breeding frequency; litter size; sex ratios; fecundity; rate of increase.

Introduction

Raoul Island is the northernmost and largest island (2950 ha) of the Kermadec group, which lies at a latitude of 29 ºS and is equidistant between the North Island of New Zealand and the Tongan Islands. It is an active volcano which last erupted in 1964, and consists of three steep-walled calderas rising to 520 m above sea level (Figs. 1,2). The climate is subtropical, with a maximum monthly mean temperature of 22.4 ºC in February and a minimum monthly mean temperature of 16.0 ºC in August. The mean annual rainfall of 1470 mm is spread throughout the year, although the period from October to January is usually drier than the rest of the year.

To give some protection to the indigenous biota, the New Zealand Government designated Raoul Island a Flora and Fauna Reserve in 1934, with 111 ha set aside for a meteorological station. The island is largely forested, with an endemic pohutukawa *(Metrosideros kermadecensis)* being the dominant canopy tree. The flora contains some tropical elements but the main species place the island in the New Zealand botanic region. Eighteen taxa of vascular plants are described as endemic (Sykes, 1977).

Three species of birds are confined to the Kermadec group, and several others are restricted to Raoul Island and similar small islands in the south Pacific (Falla, Sibson and Turbott, 1982).

It is not known when or by whom the first

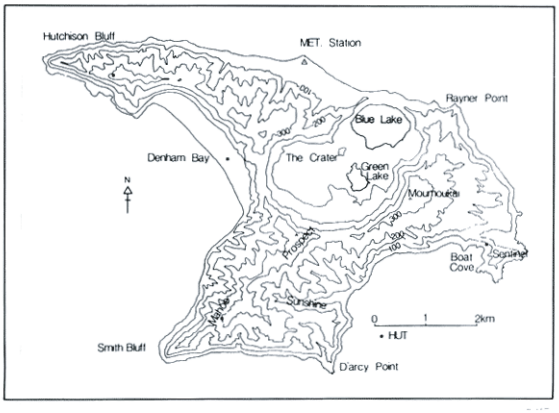

Figure 1: *Map of Raoul Island showing topography and places mentioned in the text.*

Figure 2: *Cliffs behind Denham Bay showing the dominant pohutukawa forest and difficult hunting terrain.*

goats *(Capra hircus)* were liberated on Raoul Island. In December 1836, Captain W. B. Rhodes in the whaling barque *Australian* was told by one of the island's settlers, who had themselves arrived that year, that goats and feral pigs *(Sus scrofa)* were present (Straubel, 1954). It is known that sperm whalers visited Raoul Island early in the 19th century, and they were probably responsible for liberating goats, presumably for use as supplies of fresh meat (Bates, 1922). The destruction of the indigenous flora by goats was noted as early as 1908 (Oliver, 1910), and he and later writers made pleas for the extermination of the goats (Merton, 1968; Sykes, 1969, 1977).

Goats were hunted by the various settlers who periodically inhabited Raoul Island from 1836 until 1937 (Morton, 1957; Smith, 1887), but these efforts must have had little effect on the population. After Raoul Island was gazetted as a Flora and Fauna Reserve and the meteorological station was established, more systematic hunting was encouraged. In 1937 and 1944 a man was employed to kill goats, feral cats *(Felis catus),* feral pigs, and rats *(Rattus exulans* and *R. norvegicus).* The first serious attempt at eliminating goats was made by the New Zealand Forest Service (NZFS) in 1956, but this and the recreational hunting by the meteorological station staff were not sufficient to exterminate the herd.

The problem was reviewed in 1970, and since 1972 annual hunting expeditions have been sent to Raoul Island. Each year between three and six skilled NZFS hunters, each with up to three hunting dogs, have spent 2-8 months on the island - usually from about June until November. In addition to this hunting, such alternative control methods as helicopter gunships (Challies, 1974), natural bait poisoning (Davison, 1938 unpubl.; Parkes, 1983), 'Judas' goats wearing bells (Thomas, 1982), and snaring have been tried with varying success.

This paper describes the effect of these campaigns on the density, distribution, and structure of the goat herd and estimates those demographic parameters which describe the herd's productivity - frequency of breeding, breeding rates, litter sizes, and the primary sex ratio.

Methods

The locations of 408, 255, 333 and 146 goats killed in 1976, 1981, 1982 and 1983 respectively were plotted on maps of Raoul Island. These maps were overlain with a grid representing 250 x 250 m squares and the number of goats killed in each grid square was summed for each year. The numbers on the kill distribution maps (Fig. 4 a,b,c,d) are these grid square totals, while the contours link the centres of grid squares with 1, 3, 6, 9 . . . kills. From these maps, the changing patterns of density and distribution of goats can be inferred by assuming that the number of kills in an area is roughly proportional to the density of goats in that area. This will not be a linear relationship as, although all areas were hunted each year, areas favoured by goats and/or hunters were hunted more frequently so that their relative importance will be over-emphasised.

In 1972, 1979, 1981, 1982 and 1983, some goats were autopsied; the date on which they were killed was usually recorded and the following information noted:

(i) In 1972, 155 goats (80 F) of the 1286 killed during August-October were autopsied by staff from Ecology Division, DSIR. Among other measurements, they noted whether females were lactating, the presence, sex and weight of embryos, and they collected and tagged one lower jaw from each goat (Rudge and Clark, 1978).

(ii) In 1979, 220 goats (108 F) of 411 killed during July-December were autopsied by NZFS hunters. One lower jaw was extracted, tagged and returned to New Zealand, and a note taken of the reproductive status of females and the number of embryos.

(iii) In 1981, 112 goats (63 F) of 211 killed during July-November were autopsied by the hunters. The same procedure was followed as in 1979; however only 83 of the 112 jaw tags remained attached to the appropriate jaws.

(iv) In 1982, 233 goats (126 F) of 341 killed during June-December were autopsied by the hunters. Again, basic reproductive data and jaws were collected, and in addition, the length and sex of embryos from 37 females were noted.

(v) In 1983, 81 goats (48 F) of 147 killed during April-December were autopsied by the hunters. The 1982 procedure was repeated, the length and sex of embryos from 10 females being recorded.

The autopsied goats were assigned to one of four age classes according to the eruption and replacement sequences of their permanent and milk teeth (Habermehl, 1961), namely kids; 6-12 months; 13-24 months; and, 25 + months.

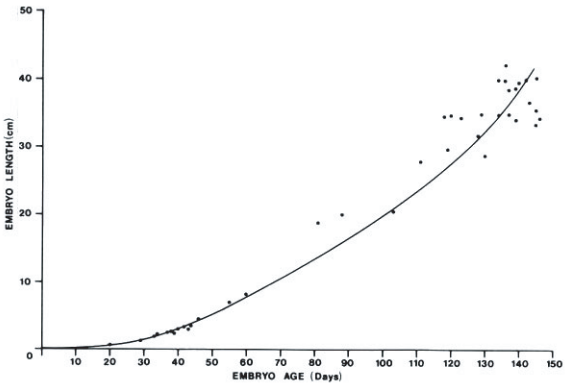

Figure 3: *Goat embryo length/age curve derived from data given by Harrison* (1948) *and Eaton* (1952).

Embryos were aged and conception dates calculated from the embryo length/age curve (Fig. 3), which was drawn free-hand through data given by Harrison (1948) and Eaton (1952). Because hunters did not report embryos less than 2 cm long (about 35 days old, Fig. 3), the period during which pregnancy was detectable is taken as 115 days, based on a gestation period of 150 days (Peaker, 1978).

The NZFS hunters were instructed to autopsy all goats they could reach without affecting their hunting efficiency. Thus, goats shot on inaccessible bluffs, during chases after groups of animals, or from helicopters were not autopsied. Most of the snared goats were not autopsied because they were too long-dead. The goats shot may not be representative of the whole herd, but those autopsied will at least be representative of those shot.

Results

Changes in goat density

When Rhodes visited the Island in 1836 he was told that "a few goats were present", although he saw none (Straubel, 1954). These goats must have increased rapidly over the next few decades as Smith claimed in 1887 that "goats abounded everywhere" .

The number of goats on Raoul Island has never been objectively estimated. Guesses have ranged from 4-5000 in 1936 (Venables, 1937), 2000 in 1954 (L. C. Bell, 1954 unpubl. Wildlife Service file 52/1), 800-1000 in 1955 (N. Bonnington, 1955 unpubl. Wildlife Service file 52/1), 3200 in 1967 (Sykes, 1969) and 3000 + before the hunting in 1972 (Clark, 1974). Some of these guesses were obviously too low to sustain the known harvests (Table 1), demonstrating the difficulties experienced by even skilled observers in estimating animal numbers in forests.

Although the annual kill rates (Table 1) are not directly comparable because of varying hunter ability, weather, state of facilities such as huts and tracks, and duration of the expeditions, there is a downward trend in the total annual kill and number killed/man day since 1972. Towards the end of the 1983 campaign, the hunters had difficulty finding any sign of goats despite intensive efforts, and the expedition leader was able to report that "extermination is almost within reach".

Changes in goat distribution

The progressive reduction in goat numbers over the last decade and possible changes in the survivor's behaviour have resulted in broad changes in the distribution of goats. When Raoul Island was uninhabited and/or unhunted, goats were widespread. Wray (1952), for example, was "greeted [on the beach] by a dozen or so goats, who looked at us with undisguised curiosity" when he visited Raoul Island in the early 1930's. However, once regular hunting began, goats in the easily accessible areas such as the terraces around the meteorological station, were soon eliminated or driven out (Sorenson, 1944 unpubl. Wildlife Service file 52/1). Similarly, Schofield (1972, unpubl. NZFS file 90/20) reported many goats around Green Lake in 1972, but since 1974, hunters have reported few goats from the relatively open, flat areas in the Crater.

The four kill-location maps (Fig. 4 a,b,c,d) give some indication of the contraction of the population's distribution, especially in the southern part of the island between Smith Bluff and D'Arcy Point. In 1976, goats were shot over most of this area, but by 1981, none were found about the easier terrain near the ridges, and by 1983 most survivors lived on the steeper coastal bluffs. Areas of persistent use and long-term absence are also shown by the four maps. As an example of use, the crater wall above Blue and Green Lakes under Moumoukai has always harboured goats and yields an annual harvest. Conversely, Sentinal has not been used by goats since at least 1976, although it is searched each year.

Table 1: *Goats killed and hunting effort on Raoul Island, 1937-1983.* (** Includes some goats killed by other Government agencies involved in a feral cat control programme.)*

Year	No. killed by Met. Stn. staff	No. killed by NZFS hunters	Kills/man/day (NZFS)	No. killed from helicopter	No. snared	Total no. killed
1937	676					676
1938	150+					150+
no records						
1944	844					844
no records						
1956	125	1,422				1,547
1957	54					54
1958	261					261
1959	215					215
1960	351					351
1961	544					544
1962	372					372
1963	475					475
1964	926					926
1965	339					339
1966	122					122
1967	230					230
1968	348					348
1969	462					462
1970	223	82	6.83			305
1971	347					347
1972	294	1,286*				1,580
1973	180	627*	1.83			807
1974	24	712*	2.93			736
1975	21	829	1.38			850
1976		408	1.17			408
1977		447	0.59			447
1978	130	460	1.12	8		590
1979		411	0.57			411
1980		157	0.37			157
1981		211	0.46	43	9	263
1982	26	315	0.47			341
1983		104	0.10	33	10	147

Limited evidence from a few 'Judas' goats equipped with bells on Raoul Island (R. Halsey, pers. comm.) and from home range studies on feral herds in New Zealand (Riney and Caughley, 1959; Kilgour, 1980) indicate that goats have relatively small, fixed ranges. The areas of persistent use therefore may represent discrete range areas on which future hunting efforts could be concentrated.

Group size

During 1981-1983, at least one animal was shot from each of 227 groups, the average size of which was 2.95, ranging up to 14 in the largest. On average, 19% of goats seen escaped, and, as might be predicted, in the larger groups a greater proportion escaped (Fig. 5). Mean group sizes (±95% C.L.) in 1981, 1982 and 1983 remained similar at 3.29±0.29; 2.74± 0.18 and 3.24± 0.50 respectively ($P_{1,3} = 0.79$, N.S.).

Season of births

Adequate samples of the reproductive status of females and conception dates (Table 2) were obtained only for the period July-November. Therefore the season of births cannot be calculated directly as it clearly extended beyond this period. However, some inferences can be drawn from the calculated frequencies of conception and from the monthly proportions of pregnant and lactating animals.

From the conception dates, it can be assumed that the breeding season extends from January until September, with most activity in April-June. The season of births, five months later (Peaker, 1978), is therefore, from May until January, with

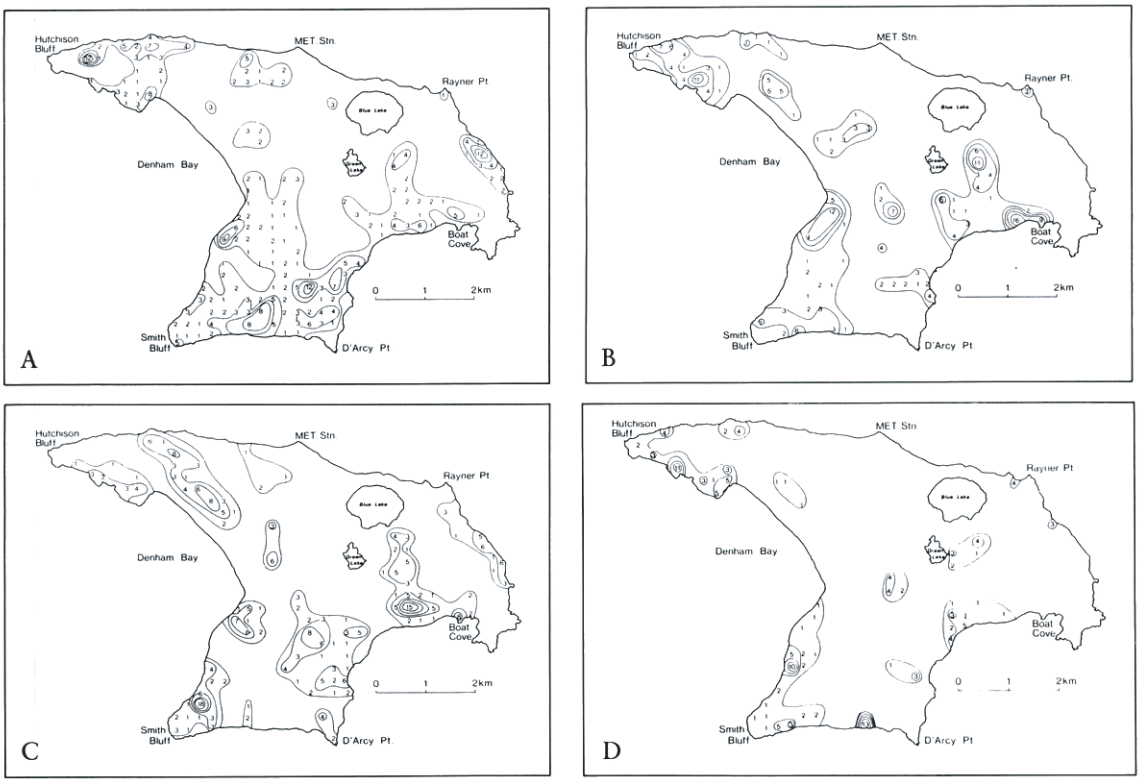

Figure 4: *Number of goats killed in 250 x 250 m grid squares and derived kill density contours through multiples of three kills. A - 1976; B - 1981; C - 1982; D - 1983.*

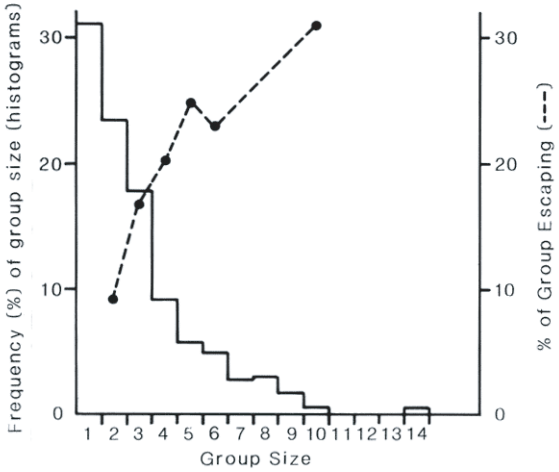

Figure 5: *Frequency of group sizes from which at least one goat was shot and percent escaping. Raoul Island goats, 1981-1983.*

an estimated 69% of kids being born from August to October. The decreasing proportion of pregnant females and the increasing proportion of lactating females from July to November also indicate that this period is the season of births.

Frequency of births

Pregnant females were found in all months for which samples were adequate (Table 2), and probably would have been found throughout the year, judging by the monthly frequencies of conceptions. Since gestation takes only five months but the breeding season extends over nine months, the production of two litters within a year is possible. As 66 females (23%) shot in 1979, and in 1981-83 were simultaneously pregnant and lactating, it is probable that some Raoul Island goats breed twice within a year. However, I have no information on the length of the lactation period, and cannot say whether any

Table 2: *Monthly reproductive state of female goats older than six months and the frequency of conceptions and births from 49 litters, Raoul Island, 1979, 1981-1983.*

		Proportion of monthly total					
Month	Sample size	Pregnant only	Lactating only	Pregnant and lactating	Not breeding	Percent conceptions	Percent births
January	1		1.00			2.0	2.0
February	0					4.1	0
March	0					14.3	0
April	1				1.00	22.4	0
May	9	0.33	0.44	0.00	0.22	26.5	2.0
June	10	0.50	0.40	0.00	0.10	20.4	4.1
July	33	0.21	0.18	0.42	0.18	6.1	14.3
August	64	0.16	0.38	0.36	0.11	2.0	22.4
September	45	0.20	0.49	0.22	0.09	2.0	26.5
October	60	0.13	0.52	0.17	0.18	0.0	20.4
November	43	0.05	0.63	0.19	0.14	0.0	6.1
December	6	0.00	0.33	0.17	0.50	-	2.0
Undated	11	0.27	0.55	0.09	0.18		
TOTAL	283	0.17	0.45	0.23	0.15		

of these goats could still have been lactating after a birth in the previous year, rather than after an earlier birth within the year. If I assume that this 23% bred twice within the year, as 85% of females breed at least once per year (Table 2), the average female would produce 1.08 litters per year.

The frequency of births may have increased since 1972 when, although 82% of adult females bred at least once per year, only 1.5% of females were simultaneously pregnant and lactating, i.e., the average female produced 0.84 litters.

Sex ratios

Eighty-three embryos from 58 litters recorded in 1972 (M. R. Rudge, pers. comm.) and in 1982-83 on Raoul Island (Table 3) gave an overall primary sex ratio of 49 M: 34 F, which does not differ significantly from unity ($\chi^2 = 2.71$). However, in twin conceptions, more males and less females seem to be produced than expected ($\chi^2 = 7.36$, $p < 0.05$). This may be due to the small sample sizes as analysis of primary sex ratios in four other feral goat populations from New Zealand (Table 3) shows no such significant bias towards males.

However, the secondary sex ratios in the younger age classes of Raoul Island goats also showed a bias towards males. Although the differences were not significant (Fig. 6), this provides some evidence that more males than females are produced. Among goats older then

Table 3: *Distribution of sexes of embryos by litter sizes for five feral goat herds in New Zealand.* (1. - C. N. Challies, pers comm,; 2. - J. Parkes, unpubl. data; 3. - Williams and Rudge, 1969.)

	No. of litters with:								
	Singletons		Twins			Triplets			
Population	M	F	MM	MF	FF	MMM	MMF	MFF	FFF
Arapawa Island'	23	12	4	6	4				
Waipoua'	11	3							
Shotover'	12	32	10	17	13		2	2	
Macauley Island'	67	70	22	26	12				
TOTAL	113	117	36	49	29		2	2	
EXPECTED	115	115	28.5	57	28.5				
x^2	0.07 (N.S.)			3.18 (N.S.)					
Raoul Island	17	18	10	10	1		1		1

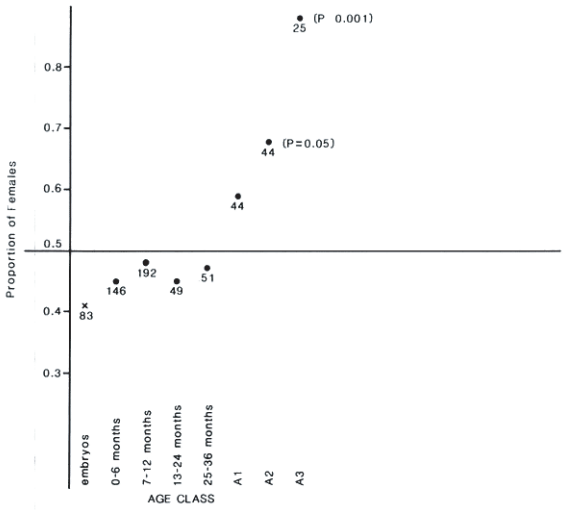

Figure 6: *Secondary sex ratios in seven age group classes of Raoul Island goats 1979, 1981-1983. Sample sizes and probabilities (where significantly different) are attached.*

three years there was a large and highly significant surplus of females (Fig. 6).

Fecundity and productivity

Table 4 shows the age-specific fecundity data for the years 1972, 1979 and 1981-83 combined, and a derived weighted estimate of productivity that includes the age-specific estimates of the frequency of births, assuming all animals simultaneously pregnant and lactating had bred twice within the year. This indicates that the herd's productivity has increased by 77%, from 96.2 kids/100 F/year in 1972 to an average of 170.3 kids/100 F/year over the last three years. This increase is attributable to a greater proportion of all age classes breeding twice within a year, a greater proportion of young animals breeding, and larger litter sizes especially among older animals.

The weighted mean productivity for the last three years of 170.3 kids/100 F/year means that 69.8 F kids/100 F/year were produced, given the observed primary sex ratio of 49:34. The finite birth rate, e^b, was therefore 1 + 0.698 and the exponential birth rate, b, was 0.529.

Table 4: *Breeding rate, frequency of breeding, litter sizes and productivity of three age classes and unknown-aged feral goats, Raoul Island, for the years 1972 (data from Rudge and Clark, 1978), 1979, 1981-83.*

Age class (months)	Sample sizes	Proportion of all F in year	Proportion of class pregnant and / or lactating	Proportion of class pregnant and lactating	No. litters per year	Mean no. embryos/ litter	No. kids/ 100 F / year
1972							
7-12	9	0.136	0.555	0	0.555	1.00	55.5
13-24	22	0.333	0.727	0	0.727	1.00	72.7
25 +	35	0.530	0.943	0.029	0.972	1.25	121.5
TOTAL	66						
				WEIGHTED MEAN PRODUCTIVITY			96.2
1979							
7-12	28	0.308	0.714	0.143	0.857	1.10	94.3
13-24	24	0.264	0.833	0.083	0.916	1.60	146.6
25 +	38	0.418	1. 000	0.395	1.395	1.60	223.2
Unknown age	1	0.011	1.000	0	1.000	3.00	300.0
TOTAL	91						
				WEIGHTED MEAN PRODUCTIVITY			164.2
1981-1983							
7-12	64	0.333	0.781	0.189	0.970	1.10	106.7
13-24	30	0.156	0.767	0.267	1.034	1.73	178.9
25 +	68	0.354	0.941	0.324	1.265	1.89	239.1
Unknown age	30	0.156	0.800	0.100	0.900	1.57	141.3
TOTAL	192						
				WEIGHTED MEAN PRODUCTIVITY			170.3

Discussion

Feral goats display a variety of breeding systems, ranging from year-round breeding in the Rimutaka Ranges (Rudge, 1969), through bimodal annual birth pulses in the King Country (Clark, 1974) or even quadrimodal birth pulses on Santa Catalina Island in California (Coblentz, 1980), to the more usual ungulate pattern of a single annual birth pulse. The 14 conception dates calculated in 1972 all fell in the period April to June (Rudge and Clark, 1978). In 1982-83, 33 of the 49 conception dates fell during this same period, with 10 before and five after. Thus Raoul Island goats have a single, but long, birth pulse usually associated with the shortening days of autumn and winter. This long breeding season means that females have the potential to breed twice within a breeding season. It is known that feral goats in New Zealand can breed more often than annually from Rudge's (1969) observations of known individuals in the Rimutaka Range.

The sex ratio of embryos showed a non-significant excess of males. However, the observed ratio of 49:34 was used in the birth rate calculations since firstly there was a significant excess of males in twin births, and secondly, the excess of males was apparent in all age classes up to three years; some evidence that an overall bias towards males is real.

The bias towards females in the older age classes may have been due to a higher, natural mortality among old males, as was found in the undisturbed Macauley Island herd (Williams and Rudge, 1969). However, there may have been a bias in sampling, i.e. old males may be more difficult to shoot as they may escape from the dogs more easily than the smaller, usually kid-encumbered females, or conversely, they may have been so easy to shoot (because their strong smell aids the dogs) that they were shot more often than old females early in the hunting campaign.

Rudge and Clark's (1978) expectations that productivity would have increased as the density of goats decreased and the food supply improved (Parkes, 1984) is confirmed by increases in many of the parameters estimated. The productivity of Raoul Island goats since 1981 was higher than those recorded in other feral herds in New Zealand. On Macauley Island, a nearby unforested island, the high density, undisturbed herd (10 goats/ha) had a similar high productivity among females older than two years but much lower productivities in the younger age classes (Williams and Rudge, 1969). Productivity of two mainland herds (Rudge, 1969; Clark, 1974) was similar to that of the 1972 Raoul Island herd, although these authors assumed only one litter per season in their calculations.

There is no valid measure of the natural mortality rates for the Raoul Island herd, but logically it is likely to have decreased as the birth rate increased. Rudge and Smit (1970) estimated an exponential death rate of 0.105 for a herd in the Rimutaka Range. Assuming this rate for the Raoul Island herd, the exponential rate of increase would be 0.529-0.105, i.e., 0.424. This rate of increase means the population would double every 20 months if hunting ceased and food was not limiting. This high rate of increase explains part of the difficulty, experienced by the island's managers in their aim of exterminating the herd, as high proportions of the herd had to be killed every year merely to keep up with the natural increase.

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