

AN ABSTRACT OF THE THESIS OF

Dawn R'Lene Seward for the degree of Master of Science in Wildlife Science presented on December 9, 1991.

Title: Use of the Judas Goat Technique to Eradicate the Remnant Feral Goat Population on San Clemente Island, California.

Abstract approved:

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Feral goat (Capra hircus) populations adversely impact native insular biota and physical habitats worldwide. The effectiveness of the Judas goat technique for eradicating remnant feral goats was studied on San Clemente Island (SCI), California from June 1989 through April 1991. By April 1991, 263 feral goats were killed on SCI; only 2 adult females and their offspring were believed to remain.

The length of time required by radio-collared (Judas) goats to establish initial contact with remnant goats was 1 to 5 days, and time to subsequent encounters with new goats averaged 3.5 days. Duration of association between Judas goats and remnant herds ranged from 1-60 days. Judas goat home ranges averaged 4.4 km<sup>2</sup> and maximum distances Judas goats traveled to find conspecifics averaged 4.8 km. Observations of Judas goats that were associated with remnant feral goats allowed individual identification of most goats and prediction of their temporal and spatial activity patterns. This knowledge greatly expedited the eradication process and likely contributed to the preservation of threatened and endangered endemic species on SCI.

Natality, survivorship, and condition of SCI goats were inversely related to decreases in population density when compared to goat populations from other islands.

higher and mortality lower than in other feral goat populations, presumably because of the unusually low density of goats on SCI.

The Judas goat technique allows removal of low density feral goat herds in a timely manner and should be used by resource managers wherever feral goats threaten native flora and fauna.

Use of the Judas Goat Technique to Eradicate the Remnant  
Feral Goat Population on San Clemente Island, California

by

Dawn R'Lene Seward

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USE OF THE JUDAS GOAT TECHNIQUE TO ERADICATE THE  
REMNANT FERAL GOAT POPULATION ON SAN CLEMENTE  
ISLAND, CALIFORNIA

1. Eradication of Feral Goats: Using and Evaluating the Judas Goat Technique on San Clemente Island, California.

INTRODUCTION

Feral goat populations adversely impacted native insular biota and physical habitats worldwide (Baker and Reeser 1972, Hamman 1975, Coblentz 1978, Daly and Goriup 1987, Vitousek 1988). Protection of affected areas was impossible without eliminating these animals. Endemic flora and fauna on San Clemente Island (SCI) have been severely degraded by feral goats since 1875 (Johnson 1975), which resulted in the listing of 4 plants, 2 birds, and 1 reptile under the Endangered Species Act of 1973 (U.S. Navy 1979). An additional 24 plant and 5 animal species on SCI have been considered for listing as threatened or endangered (U.S. Navy 1981).

Since 1934, SCI has been administered by the U.S. Navy under a Cooperative Wildlife Agreement with the U.S. Fish and Wildlife Service and the California Department of Fish and Game to conserve, protect, and manage natural resources (U.S. Navy 1990). A primary objective of the Natural Resources Management Plan for SCI is to restore native ecological conditions; feral goats must be removed to achieve this objective (Kasaty 1978).

An intensive feral goat eradication program removed approximately 28,000 goats from SCI between 1972 and 1989 (J.K. Larson, U.S.N., pers. commun.). The techniques used to control the population included trapping, herding, and hunting (Kasaty 1978). Feral goats persisted on SCI because frequent naval bombardment operations interfered with removal and rugged terrain provided cover for the remaining goats.

Techniques similar to those used on SCI have been used on feral goats in New Zealand (Rudge and Smit 1970, Rudge and Clark 1978), Australia, Galapagos Islands, Hawaiian Islands, and Mauritius (Daly and Goriup 1987) with limited success. Traditional techniques became increasingly inefficient as populations decreased. Goats are easy to eliminate if they can be found, but are difficult to locate at low densities. Cost of killing each goat increases dramatically as time required to locate individuals increases; therefore, eradication is rarely achieved. On Raoul Island, N.Z., the New Zealand Forest Service spent 2 person-years to kill the last 5 goats at a cost of \$12,500 (N.Z.) per goat (Parkes 1990). Similarly, 250 hunter-days were required to kill the last 2 goats on Isla Marchena, Galapagos Islands, Ecuador (Daly and Goriup 1987).

A recently developed approach, the "Judas goat technique", exploits the gregarious nature of goats to aid in eradication of remnant populations by allowing widely distributed groups to be located more easily (Taylor and Katahira 1988). With this technique a goat is fitted with a radio transmitter and released in an area suspected of harboring feral goats. Solitary goats have a strong drive to locate conspecifics (Shackleton and Shank 1984), and can locate other goats more efficiently than can humans. Use of Judas goats enables hunters to more quickly and efficiently locate and eradicate remnant herds.

The Judas goat technique was effectively used to locate remnant feral goats in Hawaii Volcanoes National Park (HVNP); an area typified by rugged terrain (Taylor and Katahira 1988). In Hawaii, locations of Judas goats were determined at 2-month intervals and aerial gunning from helicopters was combined with ground shooting. Taylor and Katahira (1988) reported that the Judas goat technique resulted in a 24% savings in mean cost/goat eradicated over aerial gunning alone. Although Taylor and Katahira (1988)

were able to kill goats efficiently, the 2-month time interval that elapsed between Judas goat locations increased chances for logistic complications such as transmitter loss, breeding by Judas goats, or death of Judas goats. Accordingly, my research goal was to determine effectiveness of the Judas goat technique in eradicating the remnant feral goat population on SCI.

The distribution of Judas goats in a target area would likely affect the efficacy of the technique. Effects of terrain and social interaction on feral goat home ranges and movements could, in part, determine the ability of Judas goats to locate feral goats. Taylor and Katahira (1988) did not report Judas goat home ranges in HVNP and feral goat home range size has not been described where densities were as low as on SCI. Young and Ruff (1982) found that as female black bear densities increased, home range size decreased. Conversely, Armitage (1962) reported that yellow-bellied marmots increased home range size when density increased. These studies, indicating that home ranges may be influenced by population densities, prompted the investigation of how density influenced Judas goat home range size. Furthermore, I postulated that Judas goats could locate conspecifics in much less than 2 months and that the time lag between locations could be reduced substantially from that used by Taylor and Katahira (1988). Reducing time between locations would expedite the eradication process and decrease costs.

My objectives were to (1) determine the length of time required by Judas goats to establish contact with remnant goats and time intervals between death of goats associated with Judas goats and subsequent encounters with new goats; (2) quantify the duration of association between Judas goats and remnant herds; and (3) quantify Judas goat home ranges and maximum observed distances Judas goats traveled to find conspecifics.

## STUDY AREA

San Clemente Island is located approximately 100 km west-northwest of San Diego, California and is southernmost of the 8 Channel Islands. It is 34 km long, from 1.6 to 6.5 km wide, and is approximately 148 km<sup>2</sup> in area.

Physiography of the island is rugged and rocky. The eastern side is an eroded fault scarp rising to 600 m (Kasaty 1978) with several rugged canyons extending from the highest elevation to sea level. The gently sloping west side has deep (150 m) canyons where water collects in permanent pools.

The climate on SCI is semiarid maritime with mean summer and winter temperatures of 18 and 12C, respectively (Kasaty 1978). Temperature ranges, both diel and seasonal, are approximately 6C. Average annual precipitation is 16 cm (Kasaty 1978), but 1989 to 1991 were the third to fifth consecutive years of drought. Precipitation was <8 cm per year and resulted primarily from morning fog; thus, productivity on SCI was low throughout the study.

Most of SCI is densely vegetated with several species of cacti (Opuntia spp., Bergerocactus spp.) and exotic annual grasses. Island oak (Quercus tomentella), Catalina Island ironwood (Lyonothamnus floribundus), and Island cherry (Prunus lyonii) occasionally occur in canyon bottoms.

## METHODS

The study was conducted from June 1989 until April 1991. Twelve female goats (8 in June 1989 and 4 in April 1990) were captured by net-gun on Santa Catalina Island, California and transported by helicopter to SCI. Females were used because they were more efficient than males at locating and joining remnant goat herds (Taylor and Katahira 1988). Judas goats were radio-collared and released into canyons where groups of feral goats were observed during an initial 14-day ground survey of the island. During both releases, goats were held <6 hours.

Judas goats were located once or twice each day when naval operations allowed. SCI was used for ship to shore bombardment, which restricted field access. A location was considered valid only when a Judas goat was sighted because irregular topography resulted in interference and reflection of radio signals which negatively affected accuracy of radio telemetry locations. All observations were made during daylight hours with a spotting scope or binoculars. I identified most individual goats by variations in coat color or pattern, horn shape or size, and association with other group members (e.g., juvenile with its mother). Descriptions and drawings of feral goats were recorded on data sheets, and helped identify goats that were killed, and thus, those that remained.

To assess the effectiveness of the Judas goat technique I recorded the following variables: (1) time required by Judas goats to establish initial contact with remnant herds; (2) length of time between deaths of goats associated with Judas goats and subsequent encounters with new goats; (3) duration and frequency of association changes between Judas goats and remnant herds; (4) changes in population size; (5) Judas goat home ranges; and (6)

maximum distances Judas goats traveled to find conspecifics on SCI.

Times and locations of initial Judas goat releases were recorded. Judas goats were tracked to visually determine initial encounter time (time required to first establish contact with remnant herds). There were few roads on SCI so goats were tracked on foot. Caves were common in canyon walls, and goats often used caves as resting sites. Therefore, direct observation of goats was difficult even after general locations were discerned. Contact with other goats was defined as associating with  $\geq 1$  individual (within 50 m) and having common activity such as timing and direction of movement. Times to all confirmed initial contacts were averaged.

I determined the time required for Judas goats to locate conspecifics after their consorts were eliminated (subsequent encounter time). Repeated measures analysis (Devore and Peek 1986) was used to test the null hypothesis that subsequent encounter time remained constant as goat density decreased. This repeated measures analysis tested whether the mean of the slopes of the regression lines for subsequent encounters versus time (days) differed from 0. Ten Judas goats located conspecifics a minimum of 16 times each. Two Judas goats had  $< 3$  subsequent encounters and were therefore eliminated from the repeated measures analysis.

I recorded membership of feral goat herds contacted by Judas goats, duration of associations, and frequency of association changes. Goat population size and Judas goat home ranges were determined by visual observations of goats. Focal animal sampling (Altmann 1974) was used to determine home range points for Judas goats. The minimum convex polygon method (Hayne 1949) was used to derive Judas goat home ranges. Maximum distance traveled was defined as the longest axis of observed Judas goat home ranges. Means

and standard deviations were derived for home range sizes and longest axis of home ranges. The mean home range size was used in the Spearman's correlation coefficient analysis (Devore and Peck 1986) and two-factor analysis of variance (Devore and Peck 1986) to determine if home range was dependent on length of time each Judas goat was observed and/or feral goat densities. A  $t$  test was used to determine if home range sizes differed between the east and west sides of SCI.

An initial evaluation of the Judas goat technique as an eradication tool was conducted 15-18 September 1989. Three Judas goats in 3 canyons were located 3 months after their release and goats associated with them were hunted. After an additional 5 months of data collection, an intense eradication effort began February 1990. Ground shooting was conducted throughout the study, and was combined with periodic aerial gunning after April 1990.

In February 1990, I selected a Judas goat (No. 7), to evaluate the efficiency of an individual Judas goat. Number 7 was chosen based on her potential to make rapid subsequent contacts once her associates were eliminated. All goats that number 7 encountered during a 4 day break in the bombardment schedule were eliminated.

## RESULTS

Eleven of 12 Judas goats encountered conspecifics by the first time they were located (1 to 5 days). One Judas goat (no. 10) never contacted conspecifics, perhaps because no goats were within 3.2 km of her release site, the maximum distance she traveled across her home range (3.9 km<sup>2</sup>). Mean initial encounter time was 2.4 days ( $\bar{n}$  = 13, SD = 1.4, range 1-5). Two Judas goats were moved to another area and re-released; hence, both initial encounter times were included in the above mean. Subsequent encounter times (times to locate conspecifics after previously encountered goats were killed) averaged 2.2 days (SD = 1.8 days). As goat density decreased, subsequent encounter times remained constant ( $P \geq 0.05$ ). Therefore, the ability of Judas goats to locate conspecifics was not likely density dependent within the range of densities on SCI. Judas goats continued to locate other goats even when the population was nearly eradicated ( $N < 6$  goats).

Judas goats associated with 248 individual feral goats, although several goats were contacted by more than 1 Judas goat. Because encounters by each Judas goat were treated independently, the total number of associations ( $n$  = 303) was greater than the number of feral goats encountered ( $\bar{n}$  = 248). Cumulative number of goats encountered by each Judas goat (excluding no. 10) ranged from 4 to 73 ( $\bar{x}$  = 27.5, SD = 20.6,  $\bar{n}$  = 303). Mean group size was 5 (SD = 2.8) and ranged from 2 to 17. Remnant feral goat herds maintained membership for an average of 11 days (SD = 13.8). Association time was highly variable, ranging from 1 to 60 days.

Backcalculating feral goat ages provided a population estimate of 161 goats on SCI 20 June 1989, the day this

study was initiated. During the next 16 months, 107 births were recorded. By April 1991, 263 feral goats were killed; only 2 adult females and their offspring were believed to remain on SCI.

Twenty-eight associates (57%) of 3 different Judas goats were killed in adjacent canyons during the initial evaluation of the Judas goat technique in September 1989. In this preliminary effort, 100% of the goats in 2 of the 3 canyons were eliminated, and 13% were killed in a third.

During a 4-day period in February 1990, associates of Judas goat number 7 were hunted exclusively for the purpose of determining efficiency of an individual goat. This goat contacted a new group daily and 21 feral goats were killed (approximately 10% and 100% of the extant and local populations, respectively).

Judas goat home ranges on SCI averaged 4.4 km<sup>2</sup> (SD = 2.6) and ranged from 0.7 to 11.2 km<sup>2</sup>. The mean long axis of observed home range for Judas goats was 4.8 km (SD = 1.5, range 2.8-7.1 km, Table 1). Spearman's correlation coefficient ( $r_s = .253$ ) indicated only a weak positive relationship between home range size and length of time each Judas goat was observed (range 2-16 months, Figure 1). Based on the two-factor analysis of variance, Judas goat home range size apparently does not depend on either density ( $P_d = .926$ ) or time ( $P_t = .874$ ). Judas goat home ranges were not significantly different between the east and west sides of the island ( $P \geq 0.05$ , Table 1). The lack of difference in home ranges was unexpected because the eastern side of SCI had numerous steep canyons whereas the western side had long, large, gently sloping canyons that were separated by wide sections of wave cut terraces.

Table 1. Judas goat home ranges and longest axis across observed home ranges, San Clemente Island, California, June 1989 to April 1991.

Judas No.	Aspect	Home range (km <sup>2</sup> )	Longest Axis (km)
1	East	1.07	3.50
2	East	0.69	3.02
3	West	4.61	2.83
4	West	11.16	5.02
5	East	7.07	6.10
6	West	3.43	4.02
7	East	3.04	6.31
8	East	4.84	7.05
9	East	4.84	6.69
10	West	3.89	3.24
11	West	4.89	6.05
12	East	3.58	3.71
East Side Mean ( $\bar{n} = 7$ )		5.20 $\pm$ 1.58	5.19 $\pm$ 1.71
West Side Mean ( $\bar{n} = 5$ )		4.23 $\pm$ 1.18	4.23 $\pm$ 1.31
Overall Mean ( $\bar{n} = 12$ )		4.43 $\pm$ 2.61	4.79 $\pm$ 1.57

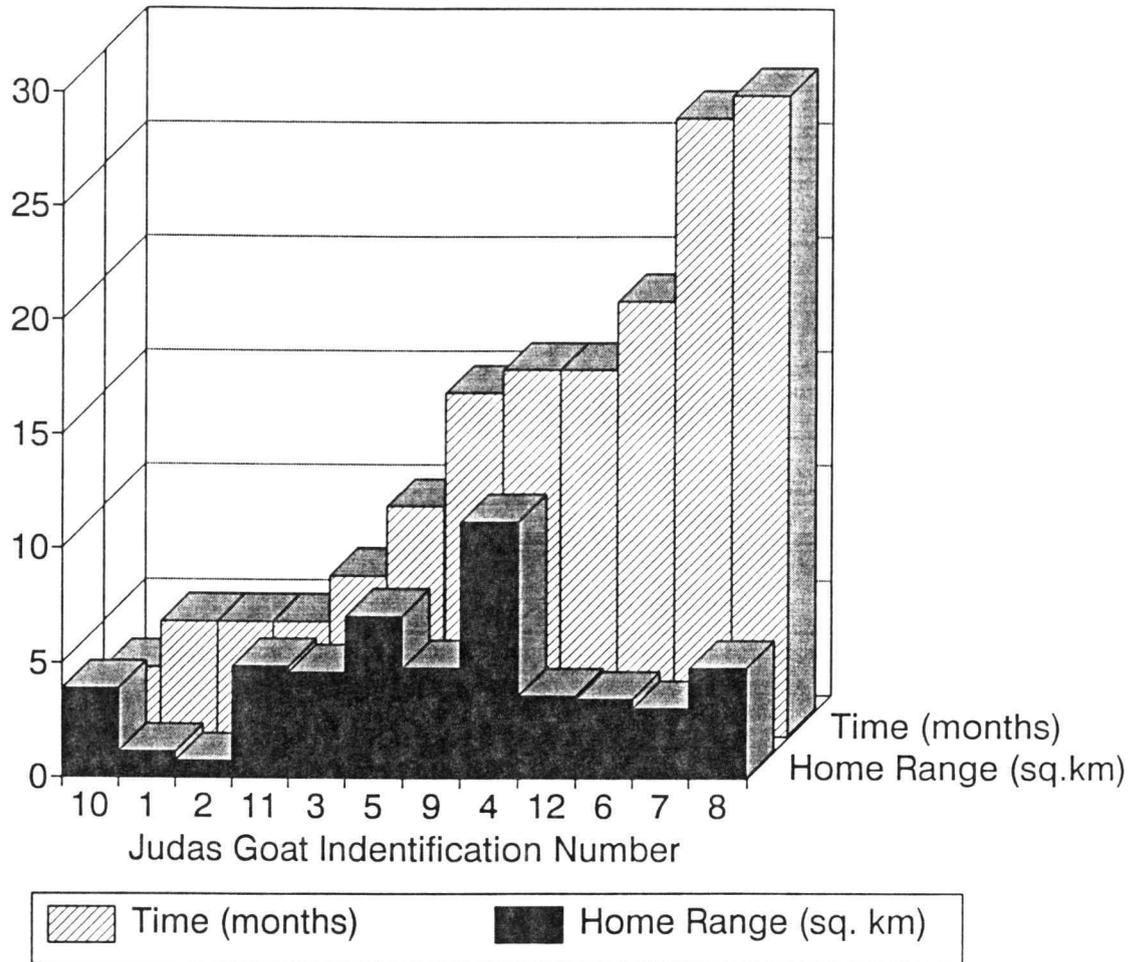


Figure 1. Length of time (months) that each Judas goat was alive on San Clemente Island, California, and its corresponding home range (km<sup>2</sup>).

## DISCUSSION

The Judas goat technique accelerated the removal of feral goats from San Clemente Island. This technique was used to eliminate 263 feral goats from SCI. During the first 12 months of the study, all Judas goat except 1 were with other goats virtually each time (often daily) I located them. Judas goats were found alone more frequently near the end of the study when few goats remained.

Only 1 Judas goat (No. 10) of 12 (8%) did not make contact with conspecifics on SCI. In contrast, Taylor and Katahira (1988) reported that 40% of Judas goats in HVNP never made contact, for reasons similar to number 10 on SCI, presumably because no feral goats were in the area of their release.

Information obtained from Judas goats allowed for prediction of temporal and spatial activity patterns and group membership in remnant herds, thereby expediting the eradication process. By locating the Judas goats regularly, I was able to record goat identities and herd compositions, and determine population size. I knew which goats remained in each area by examining carcasses. This knowledge influenced my hunting strategies, which contributed considerably to the successful eradication of goats from most canyons on SCI.

Initial visual encounter times averaged 2.4 days, but Judas goats may have encountered conspecifics well before they were visually located. The lack of change in subsequent encounter times as feral goat density decreased can be explained 2 ways: (1) my knowledge of areas frequented by Judas goats improved much over the course of the project and I was therefore able to document subsequent encounters of Judas goats with feral goats more rapidly; and (2) Judas goats may have been so proficient at locating

other goats that as long as another goat occurred within their ranging distance, they encountered it in a short period of time (usually within 6 days on SCI).

Encounter rates were likely related to distance from conspecifics, but because the precise location of feral goats was unknown at release time, the most efficient option was to release Judas goats in areas where feral goats were last seen or were historically present. Two release sites were in areas not known to contain goats, including that of number 10, which never made contact.

Undoubtedly, numerous factors contribute to the ability of a Judas goat to locate and maintain associations with remnant feral goat herds. Age of a Judas goat affected its social standing (pers. obs.); the older females were more matriarchal, (i.e., a leader, not a follower), and were therefore the most efficient Judas goats. Reproductive condition was also a factor because some post-partum Judas goats separated from other goats and associated exclusively with their offspring. To overcome this problem, offspring of Judas goats were shot as soon as possible after birth to encourage their mother to locate other goats.

Judas goats began locating other Judas goats as remnant feral goats were eliminated, presumably because there were few or no other goats remaining within the range of their movements. These Judas goat-Judas goat encounters were interpreted as an indication of the effectiveness of the technique. If a group of 2 to 3 Judas goats did not locate remnant herds within a 3 week period, 1 or 2 were either recaptured and relocated, or eliminated to encourage survivors to search for and locate remnant herds.

Judas goat behavior strengthened the conjecture that goats were extremely gregarious and quickly sought out other goats. Although effectiveness of the Judas goat technique varied with feral goat distribution and

behavioral differences, Judas goats on SCI made contact more often than reported in Hawaii (Taylor and Katahira 1988).

Home range sizes for Judas goats on SCI were generally comparable to those found for female feral goats in New Zealand (Riney and Caughley 1959), Hawaii (Yocum 1967), Santa Catalina Island (Coblentz 1974), and Australia (O'Brien 1984). Home range size did not change with decreasing feral goat densities or time. Apparently feral goat home ranges are relatively fixed within the range of densities on SCI and other oceanic islands. Taylor and Katahira (1988) did not report home range size, but suggested that home range sizes were fixed in HVNP.

Goats exhibited alarm reactions and hiding behavior in response to low flying helicopters and fixed wing aircraft. Since 1983, aerial shooting was used periodically on SCI. Consequently, it was preferable to coincide ground observations with periods of no helicopter or aircraft noise, as was also the case in HVNP (Taylor and Katahira 1988). Goats generally resumed normal activities within an hour after disturbances ended.

The Judas goat technique, when employed in a rigorous, intensive manner, was much more efficient and faster than previously demonstrated by Taylor and Katahira (1988).

## MANAGEMENT IMPLICATIONS

The Judas goat technique can facilitate feral goat removal by allowing location of remnant feral goat herds in an efficient manner. The technique allowed removal of hard-to-locate remnant herds on SCI. I recommend releasing 1 Judas goat per 4 km<sup>2</sup> because mean home range was 4.4 km<sup>2</sup>, but it may be necessary to deploy more goats in areas that are delineated by high ridges, wide plateaus, or deep canyons where discrete populations may reside (pers. obs). Based on initial and subsequent encounter times, I recommend locating Judas goats every 2 to 4 days.

An initial monitoring period during which individual feral goats and population size are identified is imperative for determining the extant population throughout any eradication program. This information will familiarize shooters with spatial and temporal activity patterns of targeted goats.

The Judas goat technique can likely be used for any size population, but traditional removal techniques may be more cost effective during the initial stages of eradication of large populations (i.e., when goats can be located in a timely manner). The 1989 remnant population on SCI was already too low to adequately assess the point at which the Judas goat technique becomes cost effective.

The Judas goat technique was used effectively for eradicating goats on SCI, and will most likely allow recovery of threatened and endangered endemic species on the island. This technique has the same potential on other oceanic islands whose biota are adversely influenced by feral goats. Eradication will provide a long-term solution to problems associated with goat-impacted environments, therefore, I encourage eradication and strongly recommend the Judas goat technique for removing remnant feral goats.

## II. Eradication of Feral Goats: Ecological Considerations.

### INTRODUCTION

The U.S. Navy instituted an intensive feral goat eradication program on San Clemente Island (SCI), California in 1972. Despite the removal of over 28,000 goats between 1972 and 1989, feral goats persisted and continued to damage native flora and fauna (J.K. Larson, U.S.N., pers. commun.). Eradication planning and implementation did not include data collection of population characteristics or goat ecology. Consequently, no data, other than numbers removed and costs of control efforts were available. Traditional eradication methods were not effective on SCI and goat responses to these methods are unknown. To better understand feral goat responses to population reductions, an intensive sustained control effort was implemented using the Judas goat technique. This procedure allowed remnant feral goats to be located and eliminated on SCI.

Hunting can be a form of compensatory mortality if breeding stock and their subsequent success are unaffected (Peek 1986). For SCI goats, the intent was that hunting mortality be additive, that is, causing mortality in excess of the populations' ability to compensate through increased natality or survivorship, and thereby reducing feral goat population densities.

Feral goats have relatively high reproductive potential; gestation is 150 days and goats reach sexual maturity at 6 months of age (Yocum 1967). Multiple births are common (Rudge 1969, Baker and Reeser 1972, Parkes 1984) and females may give birth twice a year (Rudge 1969, Ohashi and Schemnitz 1987). These reproductive traits allow feral goats to respond to population reductions with increased natality (Coblentz 1982, Parkes 1984). Parkes (1984)

documented an increase in goat productivity after population reduction on Raoul Island, New Zealand. Furthermore, Rudge and Smit (1970), using a fixed value for rate of increase, predicted that a goat population reduced by 80% could rebound to 90% of the original level in only 4 years. Feral goats have a considerable capacity to increase in number and respond to control efforts in a compensatory manner. Unless control programs are financially insured in perpetuity, protection of a natural community from the negative effects of goats requires complete eradication of feral populations. Furthermore, considering long term effects, eradication is probably less expensive and more ecologically efficient than perpetual control.

The Judas goat technique helped eliminate 263 feral goats on SCI between June 1989 and April 1991. Two-hundred and nineteen carcasses were examined to determine if natality, survivorship, and condition of SCI goats varied with decreases in population size. However, because no baseline data was available, I could only make inferences by comparing SCI goats with goats from other oceanic islands.

## STUDY AREA

San Clemente Island is located approximately 100 km west-northwest of San Diego, California and is the southernmost of the 8 Channel Islands. The island is 34 km long, from 1.6 to 6.5 km wide and is approximately 148 km<sup>2</sup> in area.

The climate on SCI is semi-arid maritime with mean summer and winter temperatures of 18 and 12C, respectively (Kasaty 1978). Average annual precipitation is 16 cm (Kasaty 1978), but 1989 to 1991 were the third to fifth consecutive years of drought. Precipitation was <8 cm per year and resulted primarily from morning fog; thus, productivity on SCI was low throughout the study.

Most of SCI is densely vegetated with several species of cacti (Opuntia spp., Bergerocactus spp.) and exotic annual grasses. Island oak (Quercus tomentella), Catalina Island ironwood (Lyonothamnus floribundus), and Island cherry (Prunus lyonii) occasionally occur in canyon bottoms.

## METHODS

The study was conducted from June 1989 until April 1991. Twelve female goats (8 in June 1989 and 4 in April 1990) were captured by net-gun on Santa Catalina Island, California, transported by helicopter to SCI, and fitted with radio-collars. These Judas goats were then released into canyons known to contain feral goats and were located as often as naval operations allowed, sometimes daily. I identified all individual goats they encountered by variations in age, coat color or pattern, horn shape or size, and association with other group members (i.e., juvenile with its mother).

An initial evaluation of the Judas goat technique was conducted from 15 to 18 September 1989; 28 goats associated with 3 Judas goats in 3 canyons were shot. After an additional 5 months of data collection, an intense eradication effort began in February, 1990. Ground shooting was conducted throughout the study, and was combined with periodic aerial gunning after April 1990.

The Judas goat technique helped eliminate 263 feral goats on SCI by April 1991. Age, sex, condition, and reproductive data were recorded ( $n = 219$ ) to determine whether the recently reduced SCI feral goat population exhibited a compensatory increase in recruitment and/or improved condition. However, because no baseline data was available, I could only compare natality and condition of SCI goats with that of goats from other oceanic islands. For comparisons, I assumed reproductive and condition parameters of SCI goats, prior to the inception of control programs, were similar to feral goats on other islands in Aldabra, Australia, British Columbia, Hawaii, New Zealand, and on Santa Catalina Island, California.

Sex was determined for 262 of the 263 goats killed and necropsies were performed on 219 (83.3%), the other 44 were

killed at locations where they could not be reached safely. The chi-squared goodness-of-fit statistic (Devore and Peck 1986) was used to determine if adult and fetal sex ratios varied from 1:1. Age was estimated to the nearest month by tooth eruption and wear (Silver 1970). Five age classes were established: birth to 0.5 year, >0.5 year to 1 year, >1 year to 2 years, >2 years to 3 years, and >3 years.

I quantified physiological condition with a subjective kidney fat index (KFI) where 1 = no fat around kidneys (poor condition), 2 = a thin layer of fat partially covering the kidneys (fair condition), 3 = a thin layer of fat surrounding the kidneys (good condition), and 4 = kidneys surrounded by a thick layer of fat (excellent condition). Mean and standard deviations were derived for comparative purposes.

For all female goats, I recorded teat condition (dry, lactating, or secreting colostrum gravidarum) and reproductive status (non-gravid or gravid uterus). Colostrum gravidarum is secreted from the teats of pregnant goats before parturition (Hafez 1980). Number and sex of fetuses in pregnant goats were recorded and crown-rump-lengths were measured to estimate fetal ages (Parkes 1984). Fetal and kid conception dates were determined (assuming a 150-day gestation period) and combined. I also noted natural mortalities in the feral goat population on SCI as they occurred.

From these data, I derived sex ratio, age structure, condition, reproductive status, production and recruitment, multiple births rates (twins and triplets), and intrinsic rate of increase.

## RESULTS

### Sex and Age Structure

The overall male:female sex ratio of 1:1.5 (Table 2) was significantly different from 1:1 ( $P = 0.001$ ,  $n = 262$ ). There were more females ( $n = 156$ , 59.5%) than male goats ( $n = 106$ , 40.5%) in the SCI feral goat population despite a male biased fetal sex ratio. The fetal sex ratio was 1:0.77 ( $n = 62$ ) and was significantly different from expected ( $P = 0.01$ ). However, the sex ratio varied from 1:2.33 for single fetuses ( $n = 10$ ) to 1:0.09 in the 4 sets of triplets ( $n = 12$ ).

One-hundred and sixty-one goats inhabited SCI the day this study was initiated. During the next 16 months, 107 births were recorded. Approximately 50% of the goats killed on SCI were <1 year old (Table 2).

### Condition

Mean KFI was 3.3 (SD = 0.9) for 219 goats (Table 3). Kids and lactating females were under the highest physiological stress (Oftedal 1985), but mean KFI for these 2 groups exceeded 3.2, which may be attributed to low population density.

### Survival

I recorded only 3 natural mortalities from June 1989 to April 1991 on SCI. A Judas goat apparently fell off a cliff, and 2 newborn goats were killed by a billy attempting to mate with their mother moments after their birth. The remaining mortalities were limited to those goats shot during the study. Excluding hunting mortality, survival rate for all age classes combined during the period of this study was 98%.

Table 2. Age and sex of feral goats killed on San Clemente Island, California, June 1989 to April 1991.

Age (years)	<u>n</u>	%	Male	Female	Sex Ratio (M:F)
0-0.5	82	32.9	40	42	1:1.1
>0.5-1	42	16.9	11	31	1:2.8
>1-2	16	6.4	4	12	1:3
>2-3	40	16.1	10	30	1:2
>3	69	27.7	35	34	1:1
<b>Total</b>	<b>249</b>	<b>100</b>	<b>100</b>	<b>149</b>	<b>1:1.5</b>

Table 3. Subjective kidney fat indices of goats >0.5 years old killed on San Clemente Island, California, between June 1989 and April 1991.

	n	KFI Value				$\bar{x}$	SD
		1	2	3	4		
Males	91	8	14	19	50	3.2	1.0
Females							
Pregnant	32	0	2	12	18	3.5	0.6
Lactating	41	0	8	11	22	3.3	0.8
Both	15	1	2	5	7	3.2	0.9
Non-reproductive	40	5	2	7	26	3.9	0.7
Total	219	14	28	54	123	3.3	0.9
Percentage	100	6	13	25	56		

### Reproductive Condition

Reproductive condition for 105 of 107 females >0.5 years of age was recorded on SCI. More than 80% ( $\underline{n} = 84$ ) of these females were pregnant, lactating, or both pregnant and lactating (Table 4). Pregnant or lactating females comprised 26.7% ( $\underline{n} = 28$ ) and 39% ( $\underline{n} = 41$ ) of the female goat population, respectively, whereas 14.3% ( $\underline{n} = 15$ ) were both pregnant and lactating. Of the 21 non-reproductive goats, 81% ( $\underline{n} = 17$ ) were <12 months old; only 4 non-reproductive females were >12 months old.

### Production and Recruitment

There were 10, 20, 4, and 20, 26, 4, single, sets of twins, and sets of triplets in utero (Fig 2a), and born on SCI (Fig 2b), respectively, from June 1989 to April 1991. Conception dates for kids born during the study were combined with fetus conception dates (Fig. 3). Feral goats on SCI bred year-round, but peaks occurred between September and December during 1989 and August and September during 1990. As the number of feral goats on SCI decreased, the percentage of pregnant females increased to 100%.

### Rate of Increase

There were at least 146 kids born to 84 adult female goats on SCI from June 1989 to May 1990; 84 were female kids. Productivity averaged 1.7 kid/female/year or 1 female kid/female/year. Using a birth rate ( $b$ ) of 1 female kid/female/year and annual survival rate of 98% (page 23), death ( $d$ ) = 0.02, the intrinsic rate of increase ( $r$ ) is  $b - d = 0.96$ .

Table 4. Reproductive condition of female feral goats >0.5 years old on San Clemente Island, California, June 1989 to April 1991.

Age (years)	<u>n</u>	Pregnant	Lactating	Both <sup>a</sup>	Non-Reproductive
June 1989- May 1990					
0.5-1.0	21	6	3	3	9
>1.0-2.0	9	7	0	2	0
>2.0-3.0	24	6	15	2	1
>3	25	4	15	5	1
June 1990- April 1991					
0.5-1.0	10	1	1	0	8
>1.0-2.0	3	1	2	0	0
>2.0-3.0	4	1	2	0	1
>3	9	2	3	3	1
<b>Total</b>	<b>105</b>	<b>28</b>	<b>41</b>	<b>15</b>	<b>21</b>

<sup>a</sup>Goats that were both pregnant and lactating, in addition to those in the pregnant or lactating classification.

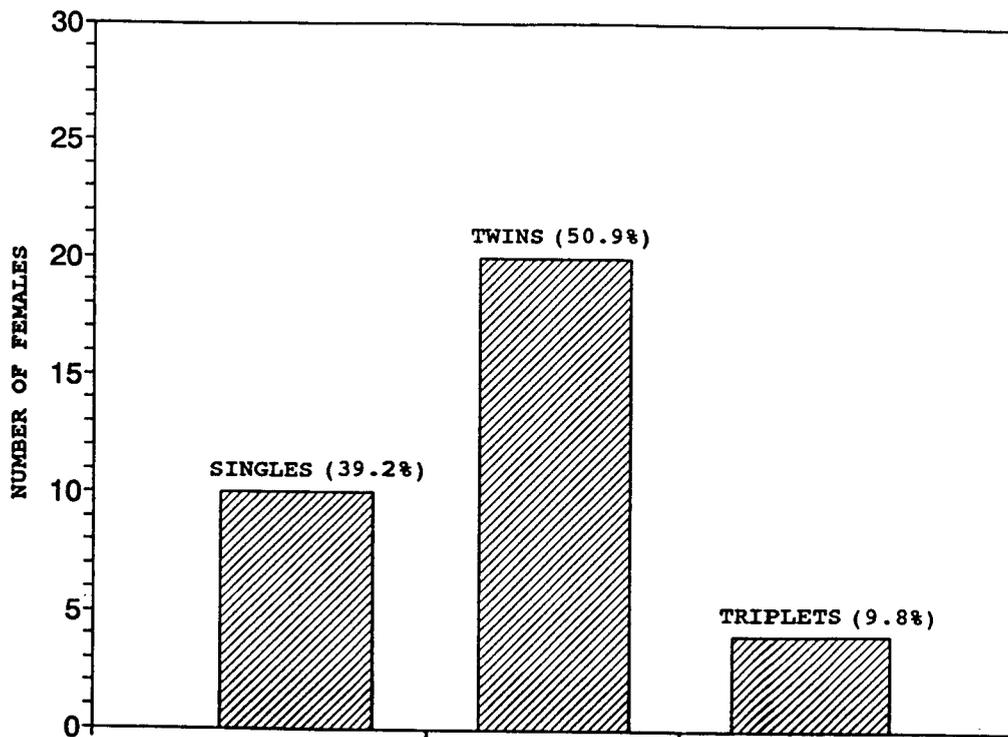


Figure 2a. Number of pregnant female goats ( $n = 34$ ) with 1, 2, or 3 embryos at death on San Clemente Island, California, from June 1989 to April 1991.

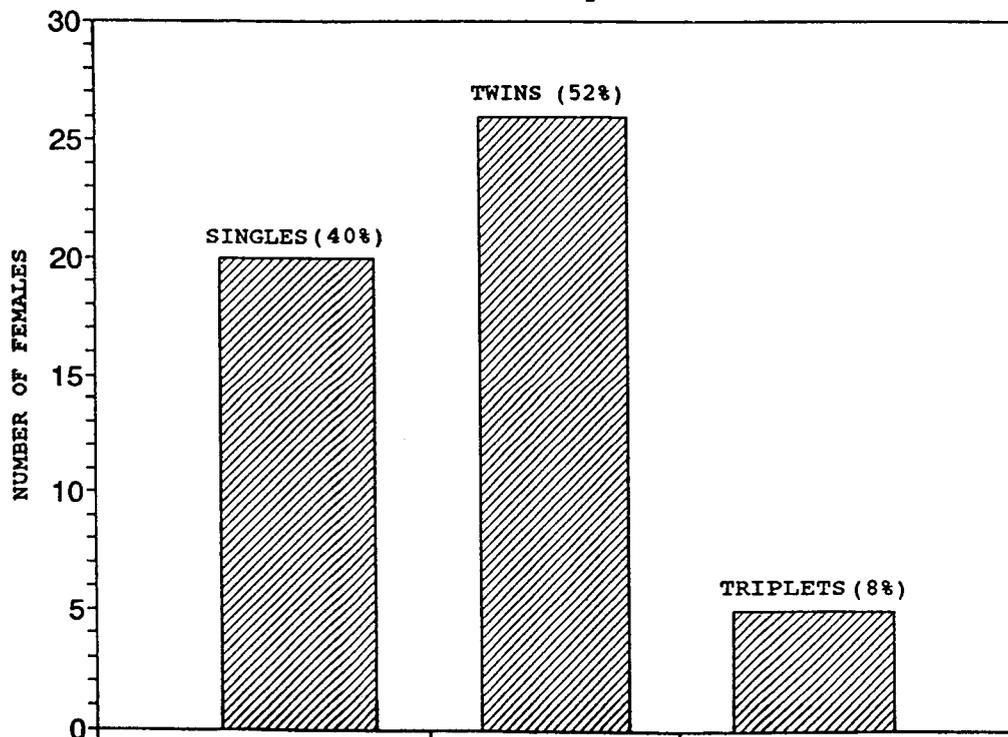


Figure 2b. Number of female goats ( $n = 50$ ) that gave birth to singles, twins, and triplets on San Clemente Island, California, from June 1989 to April 1991.

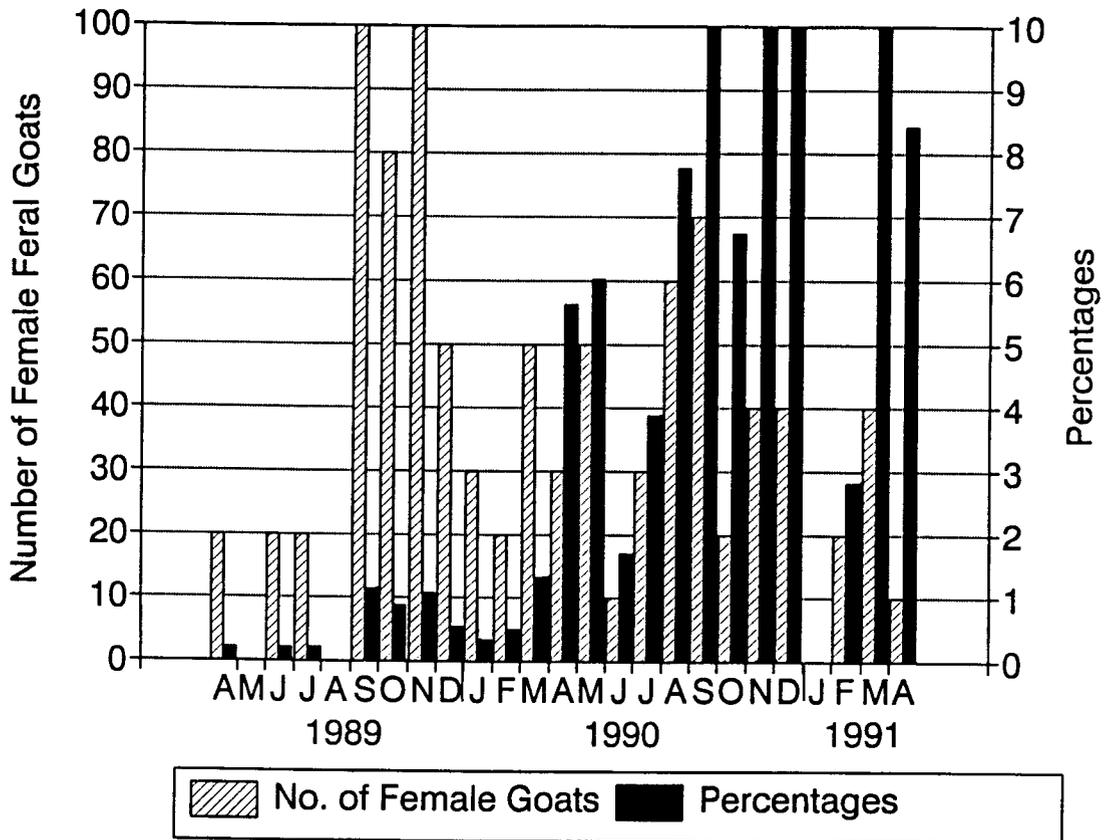


Figure 3. Conception dates for female goats that were pregnant or gave birth to kids and percentages of adult female feral goats that were pregnant or gave birth to kids on San Clemente Island, California, from April 1989 to April 1991.

## DISCUSSION

There are no baseline data for the 28,000 goats removed from SCI prior to initiation of the Judas goat project in June 1989. Therefore, I can only compare compensatory response and physiological condition of feral goats on SCI to data from other studies of feral goat populations on oceanic islands.

### Sex and Age Structure

There were significantly more female than male goats on SCI, but because the survival rate was approximately 98%, juvenile male mortality, a common explanation for female biased sex ratios (Williams and Rudge 1969, Caughley 1970, Coblentz 1982), could not have contributed much to this difference. Eradication efforts may have selectively culled more males because of morphological and behavioral differences. Because of their larger body size (Coblentz and Van Vuren 1988), horns (Williams and Rudge 1969), and beards, males were easier to see than females and therefore more likely to draw the attention of shooters. Sometimes males were exposed to shooters longer than females because they were slower to react to disturbances on SCI.

About 50% of the goats killed on SCI were <1 year old, but the lack of baseline data prevented examination of potential changes in the age structure. In contrast, goats <1 year old comprised  $\leq$  33% of hunted populations on 3 oceanic islands in New Zealand and Aldabra (Williams and Rudge 1969, Coblentz and Van Vuren 1988). However, Coblentz (1982) found a noticeably greater proportion of juveniles in a more intensely hunted feral goat population than in a less intensely hunted population (Mt. Orizaba and Coffee Pot Canyon, respectively) on Santa Catalina Island, California.

### Condition

Most goats on SCI were in excellent condition, which was probably attributable to increased resource availability brought on by low population density. Body mass, a measure of condition, of feral goats varied inversely with population density on Raoul Island, New Zealand, (Rudge and Clark 1978) and Santa Catalina Island, California (Coblentz 1982). Caughley (1970) found a similar relationship in female Himalayan thar (Hemitragus jemlahicus). Coblentz and Van Vuren (1988) found that male goats had the lowest mean condition (based on KFI) whereas pregnant females were in the best condition in 3 low density populations in Aldabra. Generally, feral goats on SCI were in good or excellent condition. Based on KFI, the condition of females that were both pregnant and lactating was equal to that of male goats ( $\bar{x} = 3.2$ ) on SCI and lower than any other group. Non-reproductive females had the highest mean KFI ( $\bar{x} = 3.9$ ), but pregnant or lactating females had means above 3.3.

### Reproductive Condition

Feral goats display a variety of breeding systems ranging from year-round breeding in British Columbia (Geist 1960), North Island, New Zealand (Rudge 1969), and Hawaii (Ohashi and Schemnitz 1987), to quadrimodal birth pulses on Santa Catalina Island (Coblentz 1980). Feral goats on SCI bred year-round, but peaks occurred between September and December during 1989 and August and September during 1990. This breeding cycle coincides with birth peaks in domestic goats from temperate latitudes (Asdell 1964). Domestic goats are seasonally polyestrous and the main breeding season occurs during the autumn and winter months (Turner 1936), but females may come into estrous year-round (Phillips et al. 1943). Rudge (1969) stated that although feral goats were capable of producing kids twice each year,

they usually do not fulfill this potential. .

I found that more than 16% of females in 2 age classes ( $n = 73$  and  $62$  for  $>1$  to 2 years and  $>2$  to 3 years, respectively) were simultaneously pregnant and lactating. This frequency was slightly lower than the 20-30% identified in 3 other insular feral goat populations (Williams and Rudge 1969, Coblentz 1974, Parkes 1984). Based on the number of females that were both pregnant and lactating, I suspect that several SCI females would have had a birth interval of 180 days, similar to that noted by Ohashi and Schemnitz (1987) in Hawaii.

#### Production and Recruitment

Fourteen female goats on SCI were either pregnant or had given birth by the time they were 12 months old (8 singles, 6 twins). However, reproduction by goats  $<12$  months old was commonly reported in feral goat populations (Geist 1960, Yocum 1967, Rudge 1969, and Rudge and Clark 1978). Multiple births were also common (Rudge 1969, Baker and Reeser 1972, Parkes 1984). On SCI, I recorded 4 sets of triplets in utero, and 4 other females produced triplets. This relatively high occurrence of triplets was unusual because triplets were only recorded 5 times in the literature (Parkes 1984, Burke 1988). Furthermore, the condition of a Judas goat from Santa Catalina Island improved enough for her to produce 1 of the sets of triplets merely 4 months after being released on SCI. Production of triplets on SCI was extraordinary in light of the fact that single births were far more common than twins on Santa Catalina Island (Coblentz 1982), and triplets were never recorded.

Twinning rates for fetuses in utero (51%) and kids (52%) on SCI fell within or above the range for other feral goat populations (50% in Hawaii, (Yocum 1967); 52% in utero and 25% of births in New Zealand, (Rudge 1969); 30.5% in

another New Zealand population, (Williams and Rudge 1969); 26.1% to 80% on Santa Catalina Island (Coblentz 1982); and 21.4%, 22.2%, and 60%, for 3 islands in Aldabra (Coblentz and Main 1988)). The combination of twinning rate and triplet rate (in utero = 9.8% and kids born = 8%) during the study on SCI brought the overall multiple birth rate to approximately 60%.

Ohashi and Schemnitz (1987) concluded that the ability of females to kid twice in the same year depended on physiological condition. Approximately 7% (n = 4) of female feral goats >12 months old, all of which were in excellent condition, gave birth twice in a single year on SCI. Another female had 3 sets of kids within 11 months. She gave birth to 2 female kids and 5 months later, she had 2 more kids. Six months later, she had 2 more kids; at which time the first kids were 11 months old. One month later, each of the first 2 kids gave birth to twins. Essentially, 10 goats were produced from 1 adult female goat in 1 year. The last 2 sets of twins from the original female were killed within 2 weeks of birth, which likely induced a post-partum estrus in the mother. This individual was an exceptionally prolific goat and most female goats on SCI did not produce kids twice a year, however, success of eradication efforts prevented determination of long term reproductive capacity.

#### Rate of Increase

Hunted populations of goats often have high reproductive rates. Parkes (1984) documented an increase in productivity of goats after population reduction. As the feral goat population decreased on SCI, the percentage of pregnant females increased to 100%. Rudge and Smit (1970) derived a recruitment rate of 1.7 kids/female/year for a hunted population in New Zealand that was similar to that on SCI. Lower recruitment was reported by Coblentz

(1982) on Santa Catalina Island, California (0.75 births/females /year) and Yocum (1967) in Hawaii (100-164 kids/100 females). Rudge and Smit (1970) determined a minimum estimate of  $r = 0.375$  and predicted that a New Zealand feral goat population reduced by 80% would increase to 90% of the former level in 4 years. The intrinsic rate of increase for goats on SCI ( $r = 0.96$ ) was twice that found in New Zealand. At this rate, assuming a survival rate of 98%, a population of 100 goats on SCI would double in <8 months and reach approximately 680 goats in 2 years. In comparison to goats in New Zealand (Rudge and Smit 1970), if the SCI goat population was reduced by 80%, it would increase to 930% of the original population in 4 years.

The combination of high twinning and triplet rates, early reproductive maturation, a postpartum estrus in some individuals (Watts and Conley 1984) that allowed production of offspring twice a year, and low kid and juvenile mortality allowed near maximum population growth rate for SCI goats.

Because of their high reproductive potential, goats are capable of achieving rapid population increases even after the most effective control efforts (Rudge and Smit 1970, Baker and Reeser 1972, Watts and Conley 1984). When feral goats are culled, remaining goats experience reduced competition for existing resources. Incomplete eradication only culls static populations, stimulates breeding, and may result in short-term population increases (Rudge and Clark 1978).

In addition, as a goat population decreases, the amount of vegetative cover increases making remaining goats more difficult to locate for 2 disparate reasons: (1) they are simply more difficult to locate visually; and (2) they move less frequently and for shorter distances because of increased forage availability. Parkes (1990) advocated

quick eradication because the long hunting campaign in New Zealand allowed the forest understory to regenerate, thereby restricting access and visibility. In addition, with increased food availability, goat breeding rates doubled from 0.96 kids/female/year in 1972 (Rudge and Clark 1978) to 1.70 kids/female/year in the 1980's (Parkes 1984).

Based on comparisons with goat populations elsewhere, goat reproductive performance on SCI was probably density dependent; increased natality, recruitment, and individual condition, and decreased mortality resulted from decreased density. These findings support those of Coblenz (1982) on Santa Catalina Island, California and are further evidence that animal populations reduced below equilibrium densities generate a positive rate of increase through density-dependent changes in age-specific rates of fecundity and mortality (Caughley and Birch 1971, Caughley 1985, Choquenot 1990).

#### MANAGEMENT IMPLICATIONS

As remnant feral goat populations are reduced, individual reproduction increases, thereby counteracting control efforts. Consequently, I strongly advocate quick and complete eradication of feral goats over periodic control. Eradication is less expensive than indefinite periodic control because considerable hunter effort is required to constrain a population that is being induced to increase reproduction. Managers should become increasingly relentless rather than sporadic in eradication efforts as a population of goats dwindles and individuals become more difficult to locate.

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