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Increasing the efficacy of Judas goats by sterilisation and pregnancy termination

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Abstract. The use of Judas goats to locate remnant animals is a potentially powerful tool for enhancing goat-eradication efforts, which are especially important to island conservation. However, current Judas goat methodology falls short of its potential efficacy. Female Judas goats are often pregnant at the time of deployment or become impregnated in the field; pregnant females leave associated goats to give birth, causing downtime of Judas goat operations. Further, male Judas goats may inseminate remnant females. Sterilising Judas goats prior to deployment removes these inefficiencies. Here, we describe two methods (epididymectomy for males and tubal occlusion for females) that sterilise Judas goats while still maintaining sexual motivation and other behaviours associated with intact animals. These surgeries are straightforward, time efficient, and may be conducted in the field by staff with minimal training. Given the widespread and deleterious impacts of non-native herbivores to ecosystems and the importance of Judas operations in detecting animals at low densities, sterilisation and termination of pregnancy should be applied routinely in Judas goat (and possibly other species) programs to increase the efficacy of low-density control operations and eradication campaigns.

Introduction

Feral goats (*Capra hircus*) are a significant driver of ecosystem degradation throughout Australasia and on many islands throughout the world (Coblentz 1978; Parkes *et al*. 1996). Widespread loss of biodiversity has occurred from primary and secondary impacts resulting from overgrazing by feral goat populations (Coblentz 1978; King 1985; Ebenhard 1988; Desender *et al*. 1999). In response, techniques have been developed to remove feral goat populations from islands, and subsequently over 120 successful goat-eradication campaigns have been conducted worldwide (Campbell and Donlan 2005). More recently, new techniques are facilitating larger-scale goat-eradication campaigns on islands and control programs in mainland areas (Parkes *et al*. 1996; Campbell and Donlan 2005). These techniques include geographic tools, aerial hunting, and Judas goats (JGs).

A common reason for unsuccessful eradication attempts is the failure to detect and remove the final animals at low densities (Campbell and Donlan 2005). By exploiting the gregarious nature of goats, the JG method is a vital tool for detecting goats at low densities, maintaining a goat-free buffer zone, or as a monitoring tool to confirm eradication (Taylor and Katahira 1988; Campbell *et al*. 2004; Campbell and Donlan 2005). JGs are used as an accessory to other hunting methods, most commonly aerial hunting from helicopter and ground hunting with and without dogs. JGs increase the efficiency of removing animals at low densities by reducing search time for hunters in locating remnant herds (Rainbolt and Coblentz 1999). Radio-telemetry collars are fitted to select goats (JGs), which are released and allowed to seek out other goats. JGs are then radio-tracked, either on foot or by helicopter, and any accompanying goats shot (Taylor and Katahira 1988). JGs are then allowed to escape to seek out other goats, and are then rechecked at some later date. When JGs associate with other JGs, one of them must be removed to induce searching behaviours. JG–JG associations provide an indication that goats were deployed at an appropriate spacing to effectively cover the

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area, and continued associations of JGs with other JGs would indicate the absence of feral goats. While JGs have been used successfully in several eradications since its conception in the early 1980s, there has been little improvement on JG techniques (see Campbell and Donlan 2005).

The use of sterile JGs offers potential benefits to island conservation campaigns, from both management and animal welfare perspectives (Fig. 1). Female JGs often become impregnated in the field, or are pregnant at the time of capture and deployment. Pregnant females become solitary several days before giving birth, and may remain solitary with their offspring for one month to a year (O'Brien 1984). Such behaviour makes them ineffective. Female JGs must then be tracked and offspring removed to induce appropriate JG behaviours; females will quickly return to oestrus in the breeding season but become increasingly wary with the birth of future offspring, further decreasing their efficiency as JGs. Male JGs may inseminate feral females, possibly in areas where no feral males exist, jeopardising any eradication campaign. From an animal welfare perspective, JG sterilisation and subsequent increased efficacy ensures that fewer animals will be killed over time. Sterile animals offer an additional advantage if a JG cannot be located due to transmitter failure. A sterile animal presents zero risk to an eradication campaign (Campbell 2002).

Here, we provide detailed methodology for incorporating sterilisation procedures into JG programs, with the aim of improving the efficiency of island-conservation actions and mainland control programs. Using (1) a controlled field setting (University farm) and (2) an on-going island-eradication campaign (Santiago Island, Galápagos, Ecuador), we demonstrate that sterilisation of male goats via epididymectomy, and induced abortion and sterilisation of female goats using prostaglandin $F2_{\alpha}$ ($PGF_{2\alpha}$) and tubal occlusion respectively, can be effectively integrated into goat-eradication campaigns.

Background and methods

Male goats can be sterilised using a variety of methods, with effectiveness and behavioural effects varying widely. Castration (bilateral orchiectomy) causes sterility but negatively affects libido and has profound effects on other social and sexual behaviours (Hart and Jones 1975; Asa 1996; Wolfe and Baird 1997). Vasectomy is effective and has no observable effects on libido or other behaviours, but is a precise and sometimes difficult surgical procedure, making it inappropriate for field use (Beck 1973; Neaves 1975; Wolfe and Baird 1997). The injection of chemical agents, mechanically crushing the tail of epididymis, and the shortening of the scrotum to induce cryptorchidism all appear promising as sterility treatments for male JGs (Foster *et al.* 1993; Noordsy 1994; Bloomberg 1996; Morgan 1997; Wolfe and Baird 1997). However, their effects on testosterone production and behaviour need to be addressed before these methods can be considered (Sharma *et al.* 1973; Asa 1996; Bloomberg 1996). Epididymectomy is a relatively simple, fast sterilisation technique that is appropriate for field surgery with postoperative complications less common than with vasectomy (Oehme 1968; Beck 1973; Althouse and Evans 1997; Wolfe and Baird 1997). It requires minimal surgical instruments, materials, and anaes-

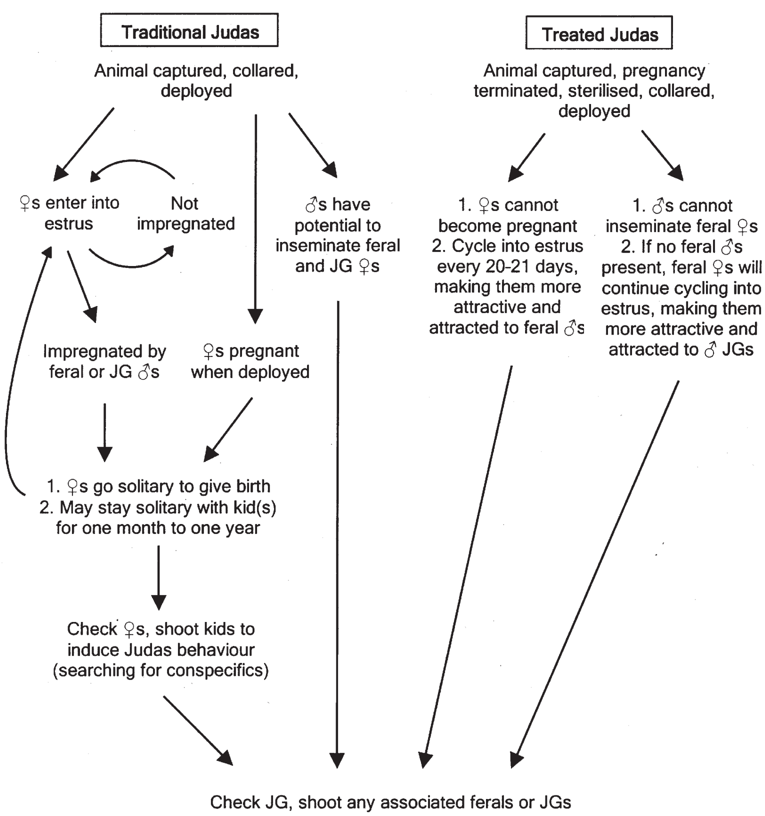

Fig. 1. The advantages of incorporating pregnancy termination and sterilisation (treated) into Judas goat campaigns compared to current methods (traditional).

thetic agents, along with no histopathologic examination of excised tissue being required (Beck 1973; Althouse and Evans 1997). Owing to the speed and ease of an epididymectomy, such an approach is applicable to mass sterilisation programs (Van Rensburg *et al*. 1963).

Methods for female sterilisation also vary. As in males, castration negatively affects libido and behaviour, while hysterectomy involves relatively complex surgery (Asa 1996; Bloomberg 1996). Intrauterine devices have been used effectively in goats but their insertion is complicated and difficult, and no applicator currently exists for goats (Gadgil *et al*. 1968). Tubal occlusion is a straightforward procedure that can be completed quickly with the use of clips and under local anaesthesia with minimal postoperative pain (Wilson 1996). The two main approaches to conduct tubal occlusion are via laparotomy or laparoscopy; the former is a simpler method that does not involve specialist equipment, although a larger incision is required (Wilson 1996).

For sterilisation to be effectively integrated into JG operations, pregnancy should be terminated before sterilisation procedures and field deployment. Termination of pregnancy facilitates sterilisation procedures and complements sterilisation by removing foetuses that would otherwise be born after deployment. Abortion is easily achieved in goats. The corpus luteum, the main source of progesterone, is essential for maintaining pregnancy throughout gestation (Braun 1997). $PGF_{2\alpha}$, or one of its analogues, interferes with the function of the corpus luteum; $PGF_{2\alpha}$ terminates pregnancy from Day 4 of conception until term; however, viable young will result from pregnancies terminated after Day 140 (Ott 1986; Braun 1997). Doses as low as 1.25 mg $PGF_{2\alpha}$ have been shown to induce luteolysis, and doses of 2.5–20 mg have been reported to terminate pregnancy (Ott 1986; Braun 1997).

The following procedures were initially carried out under controlled conditions at The University of Queensland's Gatton campus in October–November 2000 with Australian feral goats (9 males [≥two tooth] and 35 females [milk tooth – full mouth]). The same methods were then applied to JGs (42 males, 171 females [milk tooth – full mouth for both sexes]) deployed in June–December 2004 as part of a continuing feral goat-eradication campaign on Santiago Island within the Galápagos National Park, Ecuador. JGs were captured from the feral population on nearby Isabela Island and were subjected to the quarantine procedures described.

Male sterilisation – bilateral caudal epididymectomy

The buck is fitted with a hood, covering his eyes, and is restrained in lateral recumbency, exposing the testes. The scrotum is prepared for aseptic surgery by shaving and applying surgical scrub. Local anaesthesia is administered by infiltrating 2.5 mL of 2% lidocaine hydrochloride under the skin on the ventrum of the scrotum over each epididymal tail. Infiltration should be conducted at two points: under the skin and under the tunica vaginalis, where it will diffuse around the ventral region of the testis, tail of epididymis, and scrotum. Care should be taken not to pierce the epididymis or testis during infiltration as haemorrhaging due to needle puncture will make the operation more difficult.

The neck of the scrotum is grasped to force the testes distally and a 2.5-cm longitudinal incision utilising a scalpel (#21) is made through the skin and tunic over the epididymal tail (Shelton and Klindt 1974). The incision should allow the tail of epididymis to protrude, yet not allow the testis to descend through it when the animal returns to its feet (Beck 1973). The epididymis is forced through the skin incision, grasped with a pair of Babcock forceps and traction applied. The epididymal ligament joining the epididymal tail to the tunica vaginalis is severed by sharp dissection with scissors. The ligament connecting the epididymal tail to testis is then severed (Oehme 1968). Severing of the second epididymal ligament is performed by sharp and blunt dissection, with a pair of curved pointed blunt–blunt scissors repeatedly being forced between the testis and epididymal tail and spread open. Once ligaments are severed, traction on the epididymis and downward pressure on the testis with closed scissors will separate the ductus deferens and epididymal body from the testes. The tail of epididymis must be fully exposed and free of the testis, showing the start of the ductus deferens and the body of epididymis. Hemostatic forceps are placed across the ductus deferens and the body of the epididymis, which are jointly ligated with non-absorbable synthetic suture material (Oehme 1968). The epididymis is then transected with a scalpel or scissors. Care should be exercised to avoid incising the tunica albuginea of the testis, as excessive haemorrhage will occur (Wolfe and Baird 1997). The procedure is repeated on the other testis. Scrotal incisions are left open to heal by second intention, no suturing being required (Beck 1973; Wolfe and Baird 1997). Any blood is washed from the animal and the wound is sprayed with antiseptic (dipropyl isocinchomeronate) containing a fly repellent (e.g. Triclovet, Parnell Laboratories, Australia) to reduce the risk of fly strike and infection. A long-acting oxytetracycline antibiotic (20 mg kg^{-1} intramuscularly) is administered to provide three days' protection against infection.

Under controlled farm conditions four males were electroejaculated before and 25 days after epididymectomy. Electroejaculation and sperm evaluations were conducted following Memon *et al.* (1997).

Pregnancy termination and sterilisation (tubal occlusion)

Prior to sterilisation of females, a single treatment of 15 mg $PGF_{2\alpha}$ (Lutalyse, Upjohn, MI, USA, intramuscularly) is administered to all females, terminating pregnancy for those pregnant and inducing oestrus in non-pregnant females (Ott 1986). A hood is placed over the head, calming the doe and assisting in restraint. The animal's underside is shaved anterior of the umbilicus. With the use of a cradle, the goat is restrained in a dorsal recumbent position with head down at 60°; this position causes the abdominal contents to move cranially, creating space in the peritoneal cavity while exposing the reproductive organs. Legs are restrained using velcro fasteners with additional rope restraints for hind legs.

The operation site is prepared for aseptic surgery. First, 6 mL of 2% lidocaine hydrochloride is infused along the line of the proposed incision. If pregnancy is suspected, an extra 4 mL is infused a further 3–4 cm cranially in case the incision needs to be extended. An incision (5–6 cm long) is made along the line of anaesthesia. Once the muscle wall has been cautiously pierced by cutting with the scalpel the surgeon inserts a pair of rat-tooth forceps into the opening, lifting the muscle wall, and protecting the internal organs for the remainder of the incision. With index and middle fingers, one uterine horn is located and exteriorised. In pregnant females the uterine horn is large and often out of reach, thus it may be easier to locate and excise an ovary. In the late stages of pregnancy finding fallopian tubes or ovaries may be difficult, the incision can be extended and Caesarean section conducted to facilitate the procedure (Wolfe and Baird 1997). The fallopian (uterine) tube is identified and occluded using Filshie clips (FemCare, Nottingham, England). The reproductive tract is carefully manipulated back into the cavity. The procedure is repeated to occlude the second fallopian tube. The muscle wall is sutured with No. 3 chromic catgut using continuous sutures; skin being closed with staples 5–7 mm apart (e.g. Leukoclip SD, Beiersdorf AG, Hamburg, Germany). The surgical site and surrounding area is cleaned of any blood and sprayed with antiseptic spray. A long-acting oxytetracycline antibiotic (20 mg kg^{-1} intramuscularly) is administered, giving three days' protection against infection and mild cases of aspiration pneumonia. The animal is removed from the restraint cradle and hood removed.

Under controlled farm conditions, 10 females were sterilised and treated with 15 mg $PGF_{2\alpha}$ then housed for 63 days with intact free-ranging males fitted with Sire-sine crayon-marking harnesses (Iama, Cootamundra, NSW, Australia) to detect oestrus. Detected oestrus events were recorded daily. Crayon colours were changed daily. Other sterilised females ($n = 25$) were housed with intact males for 63 days to enable a failure rate to be determined.

Surgical supplies cost US$17 per female, and US$5 per male, while initial equipment set-up costs for mass sterilisation of males and females cost US$7600.

Quarantine

Passage time for 100% of seed through the gut of the goat is ~5 days (Barton and Williams 2001). Quarantine procedures for moving goats between islands should be implemented to minimise seed and parasite transfer. Goats for deployment as JGs to Santiago Island were held for seven days on Isabela Island as part of quarantine procedures to minimise the risk of seed and parasite transfer between islands. During this holding period all goats were sterilised using the methods described above. Goats were fed crushed maize or processed seed-free stockfeed, while visual inspections were conducted for external seed. Treatments for internal and external parasites consisted of 120 mg levamisol (Lev-ade, James Brown Pharma, Quito, Ecuador, intramuscularly), 10 mg ivermectin (Ivermec, James Brown Pharma, Quito, Ecuador, subcutaneously) and washes with 1.05 mg amitraz (Amitrasyn, CC Laboratorios, Quito, Ecuador).

Results

Controlled farm trials

The four males that were electroejaculated demonstrated high sperm counts with high progressive motility prior to epididymectomy. Twenty-five days after surgery, three exhibited low counts of dead sperm, while one had low levels of live sperm with poor motility. Epididymectomies averaged 25:47 ± 1:00 (min:sec ± 95% CI, $n = 7$) timed from initiating restraint to removal of hood (Fig. 2).

Males harnessed with marking crayons detected a total of 45 oestrus events, with each sterile female having at least three oestrus events. Oestrus in treated females was distributed as 67% short (<17 days, $n = 24$, 5.25 ± 1.24 days, mean ± 95% CI), 19% normal (17–25 days, $n = 7$, 20.86 ± 1.6), and 14% long (>25 days, $n = 5$, 32.8 ± 4.88) (Gordon 1997). Five females (50%) initially exhibited multiple short oestrus cycles. Female sterilisation procedures averaged 26:40 ± 1:49 for non-pregnant ($n = 23$) and 32:48 ± 5:47 for pregnant ($n = 6$) females, timed from initiating restraint to removal of hood (Fig. 2). Six females were operated on while pregnant, being treated consecutively with $PGF_{2\alpha}$. All later terminated pregnancy within 84 h (60:13 ± 13:10, h:min, mean ± 95% CI). In females sterilised for paddock trials ($n = 35$) autopsies identified two failures (5.7%). Failures were due to clips being placed on different parts of the same fallopian tube, leaving the other unoccluded; one female was pregnant, the other obese. Lack of experience likely contributed to these failures. No deaths related to surgeries occurred.

Field application – Judas goats, Santiago Island

Operation times for both male and female procedures decreased with number of operations conducted in the farm and field (Fig. 2). As operators gained experience, field operations were faster for all procedures (Fig. 2). Epididymectomies averaged 14:57 ± 1:08 ($n = 42$); female sterilisation procedures averaged 7:20 ± 2:37 ($n = 5$) for pregnant and 8:22 ± 0:37 ($n = 161$) for non-pregnant females. Three pregnant females had foetuses removed by Caesarean section to facilitate the operation and ensure that potentially

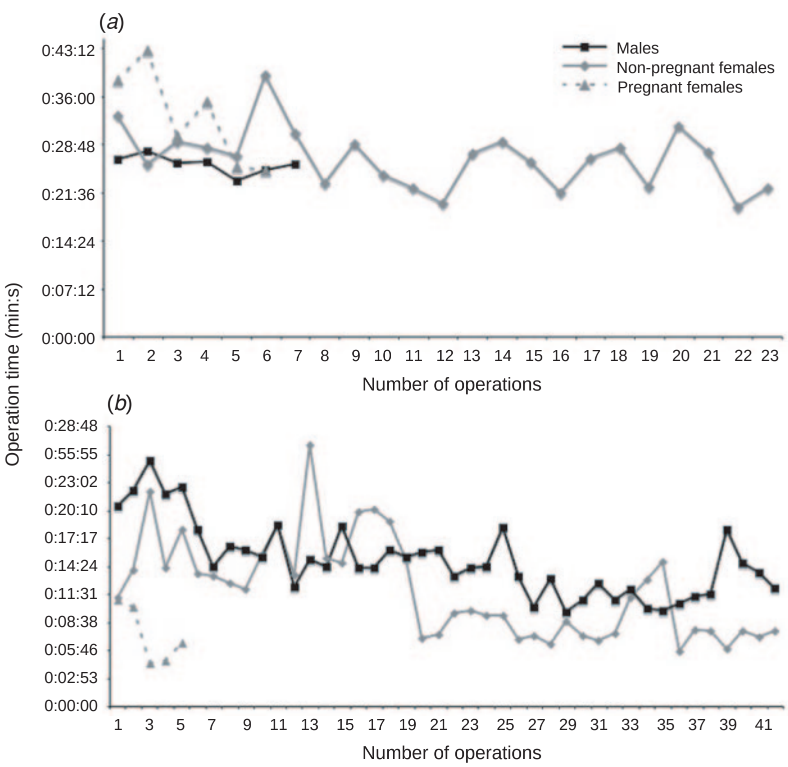

Fig. 2. (*a*) Farm and (*b*) field surgery times of male and female sterilisation. Surgery times declined for each operation type through time, as operators gained experience (see text for averages). Times for the first 41 operations are shown for non-pregnant field females; see text for global mean.

viable foetuses would not be delivered after deployment. Five pregnant females with small foetuses were deployed without abortion being observed; no kids were found 150 days after deployment (gestation length), indicating that females later aborted. Of the female JGs deployed and later autopsied ($n = 70$), two pregnant females were found (2.9%).

Discussion

Females in oestrus actively search for males and likely attract them via production of pheromones (Ramachandraiah *et al.* 1986; Muller-Schwarze 1991; Llewelyn *et al.* 1993). Sterilised females will cycle into oestrus every 20–21 days during the breeding season, increasing the frequency of oestrus events likely to occur when compared with unsterilised females that would be expected to become pregnant (Smith 1997). Goats in oestrus have been shown to increase activity 3-fold when measured using pedometers (Reed 1982). This increase in oestrus frequency and activity could be expected to increase the rate at which sterilised female JGs encounter other goats (particularly males) when compared with unsterilised females (Fig. 1).

Bilateral caudal epididymectomy and tubal occlusion appear to be an effective way to integrate a sterilisation program into feral goat eradication and control campaigns. Several additional methods were adopted in an attempt to maximise the efficiency of these methods: (1) permanent skin staples replaced suturing the skin, no ill effects were detected on animals autopsied; (2) Filshie clips are effective and faster to apply once the fallopian tubes have been identified than are other ligation techniques, and postoperative pain is considerably less with Filshie clips than other techniques (Wilson 1996); and (3) cordless clippers with blades cutting to 0.1 mm were highly effective at saving time when compared with using standard shears and razors.

Pregnancy and large internal fat deposits increase operation difficulty and time. When possible, females should be treated with $PGF_{2\alpha}$ at least 76 h prior to tubal occlusion. Pregnancy does not need to be determined, as all females are treated with $PGF_{2\alpha}$. In non-pregnant females $PGF_{2\alpha}$ induces oestrus in ~50 h (Ott 1986). Postabortion females may exhibit multiple short oestrus cycles before returning to a normal oestrus cycle (Bretzlaff *et al.* 1982). JGs should be deployed after pregnancy termination to ensure that late-term pregnancies do not produce viable kids; alternatively, Caesarean section may be employed in conjunction with sterilisation (Wolfe and Baird 1997). Failure rates of tubal occlusion can be minimised by ensuring that clips are placed on the same part of the fallopian tube in each case.

Chemical restraint (i.e. general anaesthesia) was avoided since animal recovery would be affected and the relatively minor nature of the procedures does not warrant its application. The use of a hood calmed animals dramatically. This, when combined with physical restraint and local anaesthesia was highly effective at controlling animals and likely aided in keeping postoperative mortality to a minimum. The procedures presented can be conducted in the field by staff after training by veterinarians or others familiar with these techniques. We recommend that general anaesthesia be used during training, for epididymectomy and tubal occlusion procedures, until the surgeon becomes competent with these techniques.

As females were restrained in an inverted position, the risk of aspiration pneumonia exists as rumen fluid may pass into the lungs when animals are returned to their feet. Consequently, a long-acting oxytetracycline antibiotic was used, which is effective in treating mild cases of aspiration pneumonia (Faugere *et al.* 1987). Further, broad-spectrum tetracyclines have a longer duration of action and do not require refrigeration.

Epididymectomy can be conducted effectively in other species with an exposed tail of epididymis, such as pigs, sheep (*Ovis* spp.), equids and bovines (Van Rensburg *et al.* 1963; Oehme 1968; Althouse and Evans 1997). Ligation with non-absorbable suture material and removal of the entire epididymal tail must be practiced to prevent recanalisation, maintaining long-term sterility (Van Rensburg *et al.* 1963; Oehme 1968). Larger species will likely need chemical restraint, although domestic cattle are typically epididymectomised with local anaesthetic (Oehme 1968). Sperm analysis confirms that epididymectomised goats may be capable of ejaculating live sperm until ~30 days after the operation, as has been reported for cattle (Wolfe 1986).

The techniques described here have been successfully integrated with a large-scale JG program as part of goat-eradication efforts on Santiago (58 465 ha) and Isabela (458 812 ha) Islands, where over 800 JGs have been deployed. These methods should be applied routinely in Judas programs, including potentially other species. For example, Judas pigs may be sterilised using the tubal occlusion methods described above, epididymectomy is possible and effective, and pregnancy may be terminated similarly with $PGF_{2\alpha}$ (Althouse and Evans 1997; Estill 1997). Other species may require alternative techniques to terminate pregnancy (see Youngquist 1997 for bovines, equines and ovines). The sterilisation of feral goats, and other non-native mammals, when incorporated with Judas programs should help increase the efficiency of island-conservation actions.

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