ERADICATION AND CONTROL OF FERAL AND FREE-RANGING DOGS IN THE GALAPAGOS ISLANDS

BRUCE D. BARNETT, Department of Zoology, University of California, Davis, California 95616.

INTRODUCTION

Islands are notorious for the ease with which the balance of their natural communities can be upset by the introduction of organisms from other areas. Introduced species can establish themselves quickly and successfully at the expense of native flora and fauna because the usual checks to their increase found in their home environments are often absent on islands.

Many island organisms are ill-fitted to withstand predation by or competition with introduced organisms. A characteristic of some island species that increases their vulnerability to introduced predators is their relative "fearlessness". As Darwin (1845) prophetically wrote when describing the extraordinary tameness of Galápagos animals:

> " ... What havoc the introduction of any new beast of prey must cause, before the instincts of the indigenous inhabitants have become adapted to the stranger's craft or power."

On the Galápagos, as with other remote islands lacking native predator populations, selection for behavior in native species which leads to their avoidance of predators has been relaxed and island fauna are often at their mercy.

The effect of man and the animals he has introduced onto the Galápagos has been considerable. Today, only 4 of the original 15 races of giant tortoise (Geochelone elephantopus) have any real chance of survival; fur seals (Arctocephalus australis) and sea lions (Zalophus californianus) were once hunted by the thousands; American servicemen during the World War II eliminated the entire vertebrate fauna of Baltra Island; the Galápagos hawk (Buteo Galapagensis) is today almost absent in areas of the archipelago where settlers, concerned for the well-being of their livestock, drastically reduced their numbers; and the once abundant spiny lobster (Palinurus spp.) now occurs only rarely in areas heavily visited over the years by commercial fishermen from the continent.

Some animals which were accidentally or intentionally introduced to Galápagos today run wild on many islands of the archipelago (Figure 1). Wild goats have drastically altered the floral composition of many islands due to the wide variety of plants they consume and the nature of their foraging habits. They are currently the greatest single threat to Galápagos ecology. Wild pigs (Sus scrofa) occur on five islands. They uproot tortoise nests and eat their young and eggs and eat both adult and juvenile dark-rumped petrals (Pterodroma phaegyopia). Feral horses run free on Isabela and San Cristóbal, and wild burros and cattle can be found on all of the populated islands. The black rat (Rattus rattus) occurs on seven islands, has outcompeted the native rice rat (Orozomys spp.) to extinction on all but one (Santa Fe), and is partially responsible for a serious decline in the breeding success of petrals on two others. Wild dogs and cats prey on native reptiles and birds and seriously threaten the survival of many of these rare and unique species.

Conservation of endemic flora and fauna by removal and control of introduced species is the top priority of the Galápagos National Park Service and the Charles Darwin Research Station. This paper presents a single aspect of conservation in Galápagos involving feral dogs and reports on efforts to eradicate ferals on the Island of Isabela in the Galápagos through the use of compound 1080 (sodium monofluoroacetate) and through an attempt to limit the re-establishment of feral populations by controlling reproduction in domestic dogs using a method of chemical vasectomy.

HISTORY OF CANID INTRODUCTIONS TO GALÁPAGOS

Domestic dogs were first introduced to the archipelago with the colonization of Floreana (Charles) Island by General José Villamil in 1832. Ten years later, Villamil took dogs with him when he relocated his settlement to San Cristóbal (Chatham), and since then ferals have occurred continuously on both islands (Melville 1856, Salvin 1876, Martinez 1915, Slevin 1931, 1959; Thornton 1971).

Little is known of the introduction of domestic dogs to Santa Cruz (Indefatigable) Island (Salvin 1876, Heller 1903, Beebe 1923, 1924). The first permanent settlement was established by Norwegian fishermen in the 1920s and members of the Norwegian Ulva expedition shot several wild dogs in 1925. Ten years later, feral dog tracks were discovered at Tortuga Bay on the island's southern coast (Kastdalen 1982). Dogs were also introduced during the occupation of the island by the American armed forces during World War II (K. Angermeyer, pers. comm.).

General Villamil apparently abandoned several dogs on Isabela (Albemarle) following a hunting expedition to the island in 1835, but it wasn't until 1868 that "wild" dogs were first reported there by a visiting British researcher (Salvin 1868). The communities of Villamil and Santo Tomas were established by Antonio Gil on Isabela's southern coast in 1897 and 1903 (Figure 2), respectively, and when

1986, Proceedings Twelfth Vertebrate Pest Conference (T.P. Salmon, Ed.). Printed at Univ. of California, Davis, Calif.

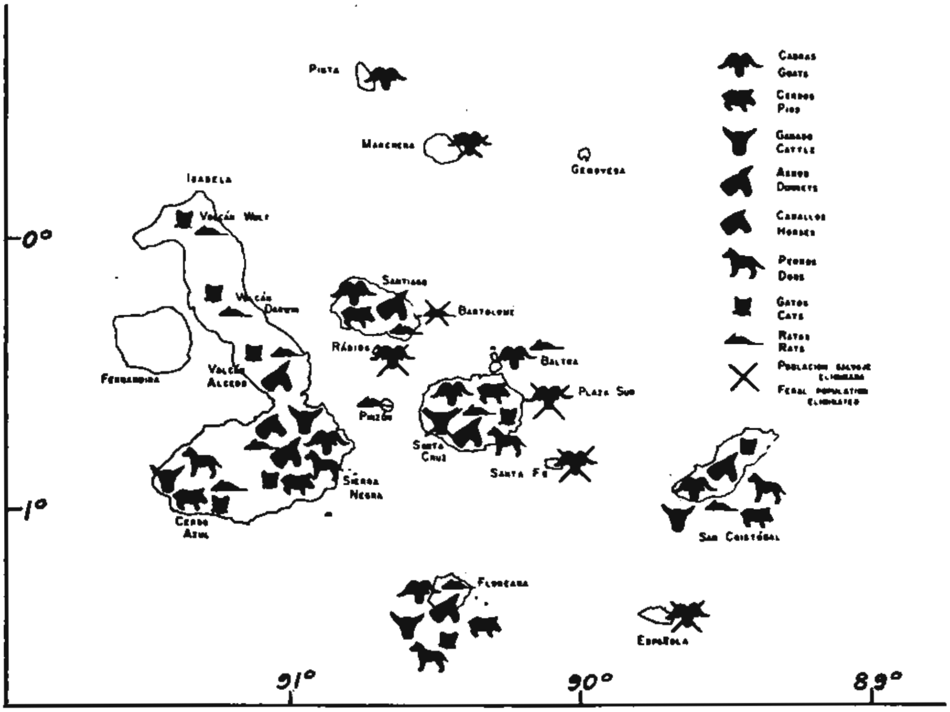

Figure 1. Distribution of feral and free-ranging domestic animals in the Galapagos.

the Stanford-Hopkins expedition visited the island in 1898, they noted the large-scale destruction of tortoise eggs by dogs along the nearby coast. In 1906, passengers on the schooner "Academy" observed wild dogs along the coast and in the highlands of the Sierra Negra volcano, near Santo Tomas, which by that time had a population of almost 200 residents (Slevin 1931, 1959). And by 1913, the increasing number of feral dogs was described as a "terrible plague" on the wild cattle populations of the highlands (Martinez 1915).

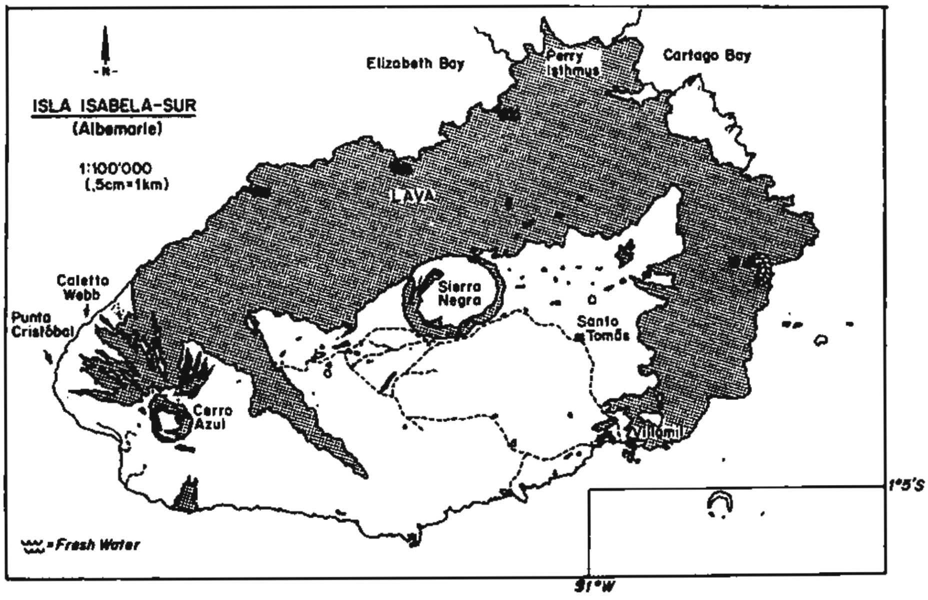

Figure 2. Southern Isabela Island.

Although some (e.g., Naveda 1950) have claimed there to be as many as 5,000 wild dogs on Isabela, more recent estimates (Kruuk 1979, Moore, 1981) suggested a total population of about 200 to 500 animals on the southern portion of the island. The likely ancestry of present-day ferals is illustrated in Figure 3.

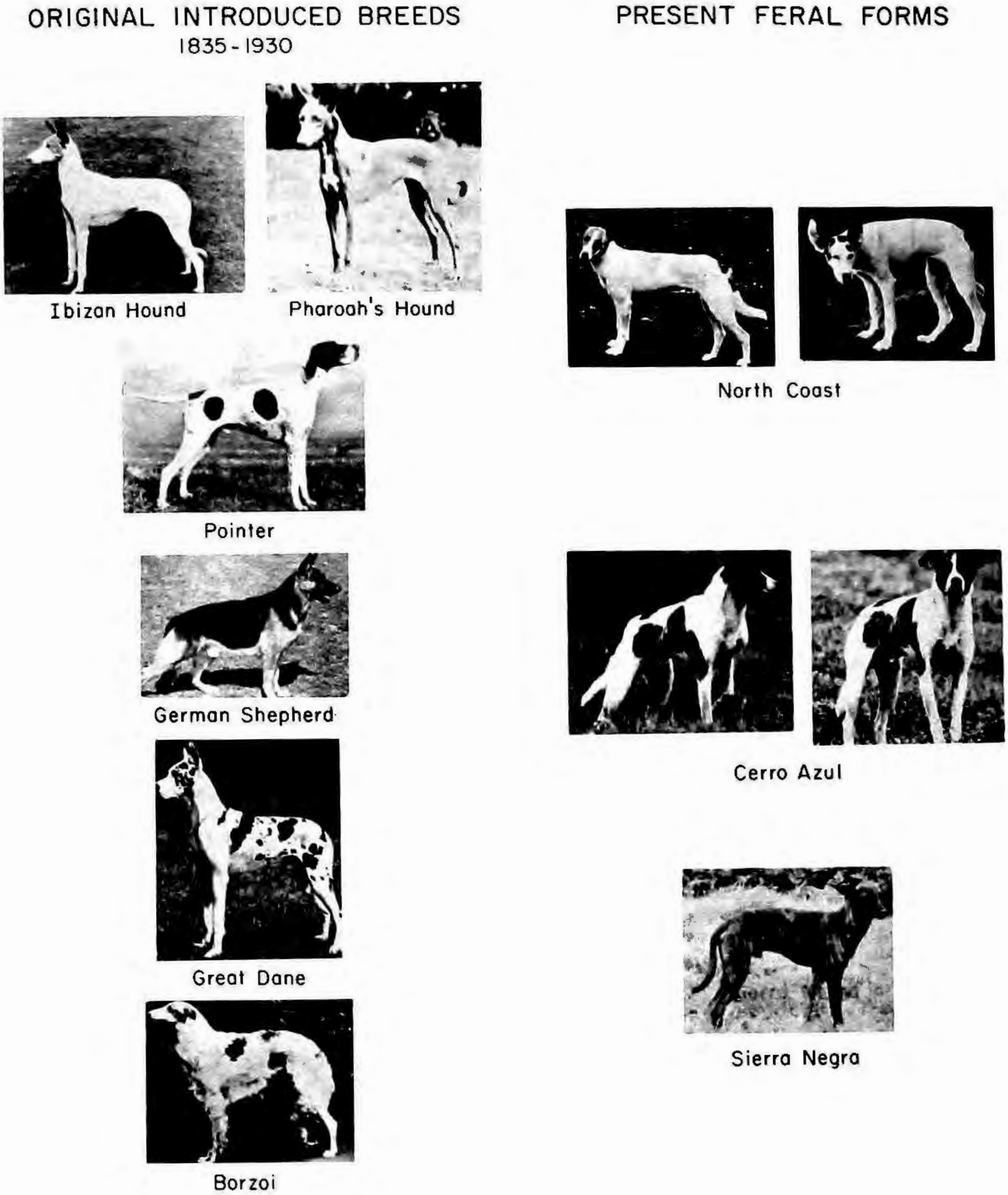

Figure 3. Ancestry of feral dogs on Isabela Island, Galapagos.

IMPACT ON ENDEMIC FAUNA

While feral dogs on Santa Cruz have never occurred in great numbers (40 to 50, Naveda 1950; Kruuk 1979), their damage to island fauna has been severe. From 1971 to 1975, dogs invaded the most productive tortoise nesting areas on the island and destroyed a vast number of eggs and the majority of young tortoises. A similar catastrophe befell the land iguana colonies on the island's northwestern coast. Dogs destroyed a large portion of that population, killing iguanas of all sizes (Anon. 1976). Ultimately, this high level of predation led to the transport of the remnant iguana population to a small islet off Santa Cruz's northwest coast ("Venicia") and many were taken to the Darwin Station where an intensive breeding program was initiated. Dog feces, more recently (1981) recovered from Tortuga Bay on the island's southern coast, contained remains of marine iguana, and in many of the samples this was the sole or dominant item.

Dogs were first reported feeding on marine iguanas along Isabela's coast, north of Sierra Negra, in 1934 by a group of American researchers (Robinson 1936). In the early 1970s, feral dogs moved into the Cartago Bay region of southern Isabela's northern coast and decimated a large resident population of land iguanas. A study of the food habits of these coastal dogs conducted prior to the recent eradication campaign revealed a diet of: marine iguana (Amblyrhynchus cristatus), Galápagos penguin (Spheniscus mendiculus), juvenile sea lion (Zalophus californianus) and fur seal (Arctocephalus australis), Audubon shearwater (Puffinus lherminieri), brown pelican (Pelicanus occidentalis) and blue-footed booby (Sula nebouxii) (Barnett and Rudd 1983).

Recent census of the marine iguana populations along this 120-kilometer coastline put their numbers at about 15,000 to 20,000 (Laurie 1981). Depending on the location of collection, between 35% and 88% of the dog feces examined contained marine iguana remains as the sole or most important item. Kruuk (1979, 1981) estimated that feral dogs in this region took approximately 27% of the iguanas in a single year, a much greater predation level than these populations could sustain.

Galápagos penguins were also a preferred food item for the dogs. The range of this penguin species is restricted to the northern coast of Isabela and the coast of Fernandina, where the cold waters of the Humboldt Current flow through the Bolivar Strait. Between 1500 and 2000 penguins occur in the region, with 500 to 900 of these occurring in areas occupied by feral dogs (Boersma 1974, Harcourt 1981). Thirty-two percent (32%) of the feces examined from coastal dogs contained penguin remains and we estimated that over 200 of these animals were taken yearly by feral dogs. Penguin populations thus appear to be severely threatened as well by intense predation from the dogs.

The possibility of a continued northward migration of dogs on Isabela, across the Perry Isthmus toward Vólcan Alcedo and along the island's northern coast, presents an imminent threat to resident populations of land iguana, giant tortoise, and flightless cormorant, the latter of which also restrict their range to this small portion of the archipelago.

ERADICATION AND CONTROL EFFORTS

The serious impact of dog predation on marine and land iguanas and penguins and the possible threat to tortoises and cormorants necessitated immediate action by the Galápagos National Park Service to eradicate feral dogs on Isabela and Santa Cruz. The residents of Floreana and San Cristóbal had apparently already eliminated the relatively few feral dogs from those islands when they became a nuisance during a drought in the early 1970s. Local farmers killed the dogs by shooting them and by applying 1080 (distributed by local health authorities for rat control) to donkey carcasses. In 1981, the Galápagos National Park Service, in cooperation with the Charles Darwin Research Station and the Frankfurt Zoological Society, began eradicating feral dogs on Isabela and Santa Cruz. The continued controlled use of compound 1080 (sodium monofluoroacetate) in this effort yielded significant success.

The rationale for the use of 1080 in the Galápagos was rather straightforward. While the shooting of feral dogs was apparently successful on islands where their numbers were not great and where their range was limited, the application of this method on Isabela Island was impractical for several reasons. 1) Isabela has an area of 2400 sq km, more than that of all of the other islands in the archipelago combined, and feral dogs range over much of the island. 2) The shooting of dogs in large groups and in areas where their numbers were concentrated tended to cause gun-shyness in animals exposed to, but not removed by this technique, thus making eradication efforts more difficult. 3) The cost of purchasing ammunition and transporting it to the islands is high and the dependability of delivery is low.

The choice of 1080 as a predacide over others, such as strychnine, cyanide and thallium sulfate, was also a result of practical considerations. 1) The use of cyanide-ejecting M-44s was rejected due to the predominantly volcanic nature of the substrate in areas where feral dogs occurred. 2) Sodium monofluoroacetate is the most selective predacide available for canids. Members of other animal species must consume a larger quantity of bait to receive a lethal dose. Therefore, by using 1080 with care, the relative risk of poisoning nontarget species is reduced. 3) 1080 was readily available to the National Park Service from the Ecuadorian Health Authorities and the cost of purchase and transportation was considerably lower than that of other predacides which would have had to have been obtained from outside the country. 4) Sodium monofluoroacetate had previously been approved by the Ecuadorian government for use in vertebrate pest control, both on the mainland and in Galápagos. A similar certification would have been necessary for other predacides before their use in the islands would have been possible. The subsequent delay in the eradication as a result of this procedure would have severely reduced the efficacy of the program.

Along with an active campaign of feral dog eradication, the Park Service and Darwin Station were also concerned with controlling reproduction in domestic dogs residing in villages bordering on National Park land. A census of domestic dogs on Isabela in 1981 and 1983 revealed a single household to support an average four animals, though some homes maintained upwards of 20 dogs.

The uncontrolled growth in numbers of domestic dogs increases the risk of their introduction into feral populations (Barnett and Rudd 1983, Kruuk 1979, Kruuk and Snell 1981) and control of reproduction in these populations is therefore an important step in the long-term control of feral dogs on the islands. Besides preying on native fauna and introduced herbivores, dogs can introduce infectious diseases and parasites and, by their sheer numbers, enhance the ease with which these organisms are transmitted[1].

Female dogs are the logical target for reproduction control, but currently available techniques are of limited effectiveness, making the application of this option on a large scale impractical and expensive. Since a successful pregnancy requires the participation of both sexes and each intact male is always potentially capable of impregnating a number of receptive females, sterilizing large numbers of male dogs could conceivably reduce the number of pregnant bitches to the point of affecting population growth.

Until recently, the only proven methods for sterilizing male dogs, exclusive of repeated hormonal applications, were surgical procedures such as orchiectomy and vasectomy, the latter of which is preferred when it is desirable to maintain high levels of aggressiveness and/or uninterrupted sexual activity in male dogs. These surgical techniques are relatively costly, however, requiring equipment and facilities not available on the remote islands of Galápagos. Similar limitations also prohibit any consideration of females as targets of reproduction control. An effective, nonsurgical sterilization technique, which is inexpensive and easy to perform, could therefore be of great value to conservation efforts on islands and in remote continental areas.

Laboratory studies have shown that injecting 0.5 ml of an aqueous solution of chlorhexidine digluconate into each cauda of the epididymides induces azoospermia in adult and prepubertal dogs, and that increasing the concentration of the solution from 1.5% to 4.5% significantly decreases the time from injection to azoospermia (Pineda 1978, Pineda and Hepler 1981). I wanted to test the efficacy of this procedure under natural field conditions and, if successful, train park wardens to carry out the procedure on islands where dogs occur in order to insure long-term reproduction control in domestic dog populations throughout the archipelago (Barnett 1985).

The technique and results of chemically vasectomizing male dogs on Floreana Island in Galápagos is briefly described here (see Barnett 1985 for full discussion). The application of this method throughout the archipelago by the Galápagos National Park Service appears to be a practical means of reproduction control in domestic dog populations.

MATERIALS AND METHODS

Coastal Eradication

Poisoned baits used along the coast for the control of feral dogs consisted of beef obtained from feral cattle in the highlands of Cerro Azul. The same day the cattle were killed, the meat was cut into thin strips (1 cm x 6 cm x 6 cm) weighing approximately 1 kg, covered with salt, placed in the sun, and dried on both sides. The night before using them, the baits were soaked in fresh water to reconstitute the meat and remove the salt and then injected with 3 mg of 1080 diluted in 1 cc of water.

The dosage of 1080 used in the meat baits was estimated from published LD_{50} for canids (Table 1) and an LD_{50} of 0.20 mg/kg was used in our calculations. The average weight of feral dogs on Isabela was 16.14 ± 5.6 kg and weights ranged from 1.5 to 28 kg (n = 92). Using a mean dog weight of 16 kg, we calculated the dosage for each meat bait at approximately 3.0 mg/kg.

The size of the baits (1 kg) was important to obtain a maximum number of dogs killed with a minimum of meat used. We were not able to see the animals actually feeding on the units. However, we did observe the caching of up to 20 by a single dog before any were eaten. From our observations of free-ranging domestic dogs in the villages on Isabela, we estimated that each animal ate from 1 to 3 kgs of meat at a sitting. We therefore wanted to insure that a dog would receive a lethal dose of poison with the ingestion of a single bait.

The lack of fresh water prevented the dogs from ranging very far inland, and thus bait stations were established every 1 or 2 km along the coast in this region of Isabela. A Zodiac® (dinghy) with a 25 h.p. motor was used to access most coastal points, but where disembarkation was difficult, sites were approached on foot.

To ensure that the feral dogs took the baits, each site was prebaited with untreated meat for 1 week prior to poisoning. A minimum of five baits was left at each station, more where dogs were concentrated in an area. Baits were set several meters apart to avoid a single dog taking more than one, and were placed under raised stones or rocks or sometimes covered with a thin layer of sand to slow desiccation of the meat and to prevent them from being found and consumed by Galápagos hawks (*Buteo galapagensis*) or owls (*Bubo virginianus*, *Tyto alba*). The stations were then marked by nearby piles of stones or shells for easy recognition.

In a few areas with large numbers of dogs, poisoned water was used with fairly good results. Again, from our observations of village dogs, we found that an individual animal drank on the average of 1 cup of water when presented with an unlimited supply. By applying 3 mg of 1080 to a cup of water (12 mg/liter) we attempted to ensure that any dog drinking from the water station would receive a lethal dose of poison. We cut the top off of a 10-gal waterjohn, buried the bottom half of the container in the sand to appear as a natural watering hole, and added 4 liters of poisoned water. This proved an

[1] Barnett, B. D. Canine heartworm (*Dirofilaria immitis*) in the Galápagos Islands. J. Parasit., in review.

Table 1. Toxicity values of Compound 1080 in target and nontarget species in Galapagos (oral route).

Species	LD50 (mg/kg)	Reference #
Man (Homo sapiens)	2.00 - 5.00	5
	0.70 - 2.10	1
Dog (Canis familiaris)	0.06 - 0.35	2
	0.10	6
	0.07 - 0.12	5
	0.09 - 0.15	3
Cat (Felis catus)	0.30 - 0.50	2,5
	0.31 - 0.52	3
Rat (Rattus rattus)	1.00 - 7.00	2
	0.10 - 1.50	1
	0.20 - 3.00	5
	0.37 - 1.04	4
Pig (Sus scrofa)	0.30 - 0.40	2
	0.40 - 1.00	1
	0.30	5
	0.84 - 1.27	4
Goat (Capra hircus)	0.30 - 0.70	2
	0.60	5
Hawk (Buteo spp.)	10.0 *	1,6
Horned owl (Bubo virginianus)	10.0 *	6
Passerine birds	0.60 - 3.00	1,6
Doves	7.80 - 14.60	1,7
Amphibians	54.00 - 500.00	1,6

* = estimated

1. Atzert, S. P. 1971. A review of sodium monofluoroacetate (Compound 1080): Its properties, toxicology, and use in predator and rodent control. Special Scientific Report - Wildlife No. 146. U.S.D.I./U.S.F.W.S.

2. McGirr, J. L., and D. S. Papworth. 1955. The toxicity of rodenticides I: Sodium fluoroacetate, antu and warfarin. The Veterinary Record 67:14-131.

3. McIlroy, J. C. 1981. The sensitivity of Australian animals to 1080 poison II: Marsupial and eutherian carnivores. Aust. Wildl. Res. 8:385-399.

4. McIlroy, J. C. 1982. The sensitivity of Australian animals to 1080 poison IV: Native and introduced rodents. Aust. Wildl. Res. 9:505-517.

5. Rammell, C. G., and P. A. Fleming. 1978. Compound 1080: Properties and use of sodium monofluoroacetate in New Zealand. Animal Health Division, Ministry of Agriculture and Fisheries, Wellington, New Zealand.

6. Wade, D. A. 1976. Standard guideline for the use and development of sodium monofluoroacetate (Compound 1080) as a predacide. In: Test Methods for Vertebrate Pest Control and Management Materials (W. B. Jackson and R. E. Marsh, Eds.). ASTM Technical Publication 625:157-170.

7. Tucker, R. K., and D. G. Crabtree. 1970. Handbook of Toxicity of Pesticides to Wildlife. U.S. Fish and Wildl. Serv. Resource Publ. #84.

effective technique, as fresh water is scarce along most of this coastline; but where poisoned water presented a potential hazard to nontarget species (i.e., hawks, tortoises, land iguanas, nesting sea birds, finches, mockingbirds, sea lions, penguins, etc., [see Table 2]), baiting with dried beef was preferred.

Feral dogs found along the coast were occasionally shot with a 22-cal. automatic rifle, but dogs occurring in groups were left undisturbed to prevent gun-shyness among any surviving animals.

Highlands Eradication

Before baiting the Cerro Azul highlands, we divided the region into zones, using natural points of reference as boundaries. One to three feral cows were killed in each zone to provide the necessary meat for baits and a minimum of 25 1-kg baits were obtained from each carcass. Each bait was injected with 3 mg of 1080 (1 cc of 1080 solution or 3 g of powdered 1080 per liter of water) and placed under the nearby vegetation, away from, but within a radius of 3 to 25 meters of each dead cow. We attempted to hide baits by covering them with grass, ferns, or other available plant material to prevent consumption by Galápagos hawks or owls. The cow's carcass was left untreated to provide food for these birds. Bait sites were always marked for easy recognition upon routine checks of the area.

General Use of 1080

Ten-eighty was always transported in a concentrated solution (3 g per liter of water) from the Darwin Station in well-sealed plastic jars, and gloves were always used in handling baits and poison. All equipment (syringes, needles, gloves, knives, etc.) was either decontaminated (by boiling for 15 min) or disposed of following use.

Data Collection

Bait stations were regularly checked for tracks, feces, and other dog sign. Records were kept on each station, including data on prebaiting success, number of poison baits, removals, dosage rates, etc.

Measurements were taken from the carcasses of any dead dogs found during the eradication and used for other aspects of the study. These data included: weight, color, sex, location of collection, approximate time of death, body (snout-vent) length, height at front and rear shoulder, tail length, ear length, and length of the left rear paw.

Skulls were also collected from each animal, cleaned and measured for subsequent age determination and morphometric analysis[2].

Chemical Vasectomy

Pretreatment semen samples were collected from nine domestic male dogs ranging from 4 to 9 years in age in order to gauge normal sperm production. Seven of these males then received bilateral injections of a 4.5% aqueous solution of chlorhexidine digluconate (0.5 ml in each epididymis). Two dogs served as controls and received an equal amount of a physiological saline solution instead of the test drug. All animals were first immobilized with a combination of ketamine hydrochloride (2.4 mg/kg) and xylazine (1.0 mg/kg), injected intramuscularly. Only enough of the mixture was used to facilitate handling and provide the necessary analgesia for injecting the test drug without inducing prolonged anesthesia.

Semen was analyzed weekly for 8 weeks after treatment to determine the number of sperm in the ejaculate, and injection sites were routinely examined to determine both short- and long-term effects of the drug. Semen samples were usually collected by manual stimulation, but due to the wild temperament of several of the test animals, manipulative means were not always reliable in producing samples of sufficient volume. In these cases, a modified portable version of an electro-ejaculator developed by Bruss et al. (1983) was used to secure semen samples from anesthetized dogs.

The data obtained from the field trials were analyzed as a two-factor ANOVA (Mixed model I) with dogs nested within the treatment groups and with repeated measures on the animals over time (Snedecor and Cochran 1967, Gill and Hafs 1971).

RESULTS

Coastal Eradication

Eight hundred and ten (810) poisoned baits were placed at the 52 stations established along the northern coast of S. Isabela, between Pta. Cristóbal and Elizabeth Bay. Of this total, we recorded 576 (71%) of these taken. Cats, rats and crabs also fed on the baits and some dogs cached a number of them before ingesting any.

Rapid evaporation limited the effectiveness of the four (4) containers of poisoned water, placed at various locations along the coast, although fresh tracks near the stations suggested recent visits by feral dogs.

We were able to locate and record data on only 57 carcasses of dogs killed along the coast. Due to the uneven terrain and the tendency of poisoned dogs to hide in caves and lava tubes, we expect that we found only a small number of the dogs actually killed by the poisoning effort. Based on observations of dog activity in the area, gathered from reconnaissance that followed the baiting of the region, we estimate that approximately 200 animals were removed in the first 3 months of the poisoning along the coast.

Highlands Eradication

We laid 819 poisoned baits along the southwestern slope of Cerro Azul, from the coast at Caleta Iguana and the tortoise reserve at Las Tablas to the summit of the volcano. Eighty-five percent (696 baits) were taken, but here, as along the coast, cats and rats also fed on the poisoned meat and a single dog was observed caching up to 20 baits from one station. We recovered 22 dog carcasses from the region, but do not expect this to adequately reflect the total number of animals killed due to the reasons previously mentioned. No further dog activity was observed during later reconnaissance of the area, and we are fairly confident that all of the estimated 80 dogs on the volcano were destroyed by the eradication.

[2]Barnett, B. D. Phenotypic variation in populations of feral dogs in the Galápagos. Evolution, in review.

The Use of Compound 1080

Ten-eighty in meat baits was the most effective method in eliminating feral dogs on Isabela. Dogs ate the meat with no hesitation, and for some time after ingestion they showed no outward effects of the poison and continued with their normal activities. During the final stages prior to death, however, the dogs appeared to suffer severe gastrointestinal discomfort, often became hyperactive, ran in circles and almost always sought out a dark place, such as a cave or lava tube, to die. Apparent hallucinations and tonic convulsions were common at this stage and the dogs seemed to lose all sense of their surroundings. Death by respiratory paralysis generally occurred 1 to 5 hours after ingestion, but more often in 3 or 4 hours. This delay between ingestion and death made it difficult to find the carcasses, as the dogs often moved considerable distances from the bait stations before dying.

With the meat baits, we found no evidence of poisoning of nontarget species. Although feral cats and black rats commonly fed on the baits, we found only one cat that apparently died from doing so. Galápagos hawks were not interested in the dried, salted baits and preferred the entrails of a freshly killed cow, although the baits were routinely hidden to prevent ingestion by the birds. Crabs were also observed feeding on the poisoned meat along the coast, but suffered little due to their high resistance to 1080. We found tracks of a night heron that apparently drank the poisoned water, but were unable to learn of the consequences of its action.

In the few cases where poisoned dog carcasses were exposed and could have been fed upon by hawks, owls, cats, rats, or other dogs, there was some potential for the poisoning of nontarget species. The ingestion of fatal amounts of poisoned dog carcasses by cats, rats, or other dogs could have occurred, but we have no evidence to support this.

Chemical Vasectomy

No difficulties were encountered in handling the test animals. The optimum drug dosage for immobilization (2.4 mg/kg ketamine and 1.0 mg/kg Xylazine) provided effective anesthesia for an average of 58 min ($\pm$ 8.91 min). Injections were normally administered with the aid of a Telinject™ blowgun system[3] to prevent injury to the handlers.

The epididymis (site of injection) was easily located by external palpation of the testis, and a pronounced firmness of the tail portion of the tubule was evidence of successful injection of the test drug.

The first effects of the treatment appeared within 24 hr after the injection and included a swelling of the testis and mild inflammation of the scrotal epithelium. These signs disappeared within 2 weeks and the subjects displayed no obvious discomfort accompanying these side-effects.

The first effects of the treatment on sperm production became apparent almost immediately and by the seventh day after injection, the number of sperm in the ejaculate dropped to about one-half of normal (Table 2; Figure 4).

Complete obstruction of the epididymis did not occur for another 4 weeks, when sperm levels decreased to zero ($F = 9.08$, $p = 0.00$). Production remained at this level for the remainder of the test period and samples collected 4 months following treatment were also azoospermic.

DISCUSSION

The Use of 1080

Sodium monofluoroacetate is highly specific for canids and has considerably lower LD_{50}s for other species occurring in areas where the poisoning was carried out (Table 2). The ages of the dogs exposed to 1080 had no apparent influence on the efficacy of the poison (McIlroy 1981). Oliver and King (1983) found temperature extremes to influence 1080's toxicity, but none of these effects were obvious in the present study. Ambient temperatures in the areas where the eradication was conducted normally range between 21° and 39°C. Dogs, however, were normally active at night or dawn and dusk when temperatures were lower and well within the range of maximum toxicity.

Unintentional poisoning of nontarget species can occur with monofluoroacetate. In most regions of the Galápagos, however, very few such potential hazards exist. Hawks, owls, and other endemic birds are highly resistant to 1080 (Table 2) and, due to the low dosage of poison in a single bait, must first find and then consume up to 4 kg of the poisoned meat for it to be of any consequence. Sally-Lightfoot crabs were observed feeding on meat baits along the coast, yet crustaceans are quite resistant to 1080 and are in little danger of being affected by the poison. Sodium monofluoroacetate sometimes exerts an emetic action in dogs, and it is possible for members of nontarget species to ingest this vomitus, especially as there is almost no leaching of the poison into the predominantly volcanic substrate in the Galápagos. This, however, was rarely observed during the eradication.

In areas close to human habitation, the use of 1080 for feral dog control is extremely dangerous to nonferal, pet and hunting dogs and is contraindicated. The residents of the highland community of

[3]Telinject USA, Inc., 16133 Ventura Blvd, Suite 135, Encino, Calif. 91436.

Table 2. Total number of spermatozoa/ml and /ejaculate (x 10^6) of control dogs and dogs given bilateral intraepidididymal injections of 4.5% aqueous chlorhexidine digluconate.

Day	No. sperm/ml[a]		No. sperm/ejaculate[a]	
	Control dogs[b]	Treated dogs[c]	Control dogs	Treated dogs
0	242.5/260.0	370.3 ± 145.7	1091.2/780.0	602.1 ± 316.9
7	155.0/267.0	153.4 ± 74.9	387.5/534.0	194.0 ± 161.0
14	240.0/355.0	18.16 ± 22.2	408.0/390.5	66.1 ± 109.0
21	317.5/265.0	10.11 ± 21.4	952.5/636.0	9.8 ± 11.2
28	137.5/222.0	0.18 ± 0.19	687.5/577.2	0.4 ± 0.34
35	122.5	0.03 ± 0.06	980.0	0.2 ± 0.46
42	55.0	0.00	1375.0	0.0
49	40.0	0.00	720.0	0.0
56	205.0	0.00	4100.0	0.0
122	450.0	0.00	13500.0	0.0

[a] number of sperm x 10^6

[b] two control dogs until day 35 (No. 1/No.6). On day 31, dog no. 6 left the farm to hunt and never returned.

[c] data expressed as mean ± standard deviation (n = 7).

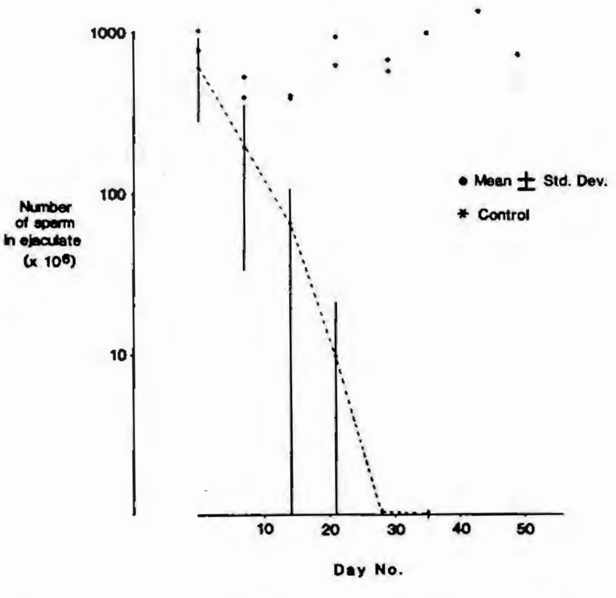

Figure 4. Disappearance of sperm in the ejaculate of chemically vasectomized dogs in the Galapagos.

Santo Tomas on Isabela use their dogs in hunting the feral cattle and pigs on the slopes of the Sierra Negra Volcano. Over 40 of these dogs were unintentionally killed during the poisoning of ferals in the region by National Park wardens.

Effects of Dog Eradication on Prey Species

Kruuk and Snell (1981) found that feral dogs along the northern coast of southern Isabela preyed mostly upon adult male iguanas. This was due to the facts that: 1) dogs were able to get closer to the large males before they would flee, 2) large males sat further from the cliff edge or some other refuge than smaller iguanas, and 3) most large males defended a territory and were thus more likely to be exposed at times when the dogs were hunting.

Dogs competitively excluded feral cats in regions where they were active, but following the dogs' removal, cats moved into the area in great numbers and proceeded to prey upon the smaller members of the iguana populations. Where the dog eradication allowed small and medium-sized iguanas an opportunity to reach full breeding status, subsequent intense predation on smaller iguanas by cats continues to severely limit the number of individuals surviving to reproductive age and, as a result, these iguana populations are still in extreme danger.

Juvenile sea lions and fur seals are no longer threatened in the absence of dogs, and populations of Galápagos penguins and nesting sea birds are also growing as a result of the eradication.

Where 1800 feral cattle occupied the southwestern slope of Cerro Azul when dogs were active, today over 3000 cattle range along this slope and threaten to overgraze the region. It is likely that the dogs played a significant role in regulating the size of this herbivore population, yet the possibility of their movement down to the coast and the resulting threat to the endemic fauna there necessitated their removal.

CONCLUSIONS AND RECOMMENDATIONS

The feral dog eradication project in Galápagos was subsidized by the Frankfurt Zoological Society and sufficient funding was made available to carry out the program for long enough to ensure that all dogs were removed from regions where they were a problem. In many cases, however, it was assumed that all dogs were destroyed in areas where no subsequent dog activity was observed during later reconnaissance. This is a common danger in such control efforts. The absence of observable activity during cursory, follow-up surveys does not always accurately reflect the true number of dogs in a region. Ferals that have acquired a bait-shyness or have somehow learned to avoid bait stations may not be apparent in areas regularly visited by eradication teams. It is therefore important that poisoning continue and alternate bait sites be established in those regions of the islands where dogs are known to exist. In fact, the greatest effort is likely to be expended to remove the last 5% of any feral population, as their reduced numbers make accurate estimation of their activity more difficult.

Children and free-ranging domestic pets suffer a high risk of exposure to 1080 in areas where its use is not carefully monitored or controlled. In the past, 1080 was easily available and used rather indiscriminately in Galápagos. Many island residents kept containers of concentrated 1080 solution in their homes, increasing the danger of exposure of children and pets to the poison. A heightened awareness in island residents of the effects and possible dangers of 1080 as a result of the feral dog eradication has already led to a somewhat more rigorous control of this substance in Galápagos. It is therefore important to precede any eradication of feral dogs in or around the villages by an intensive campaign to inform and educate the human inhabitants of the potential dangers of 1080. This simple measure could significantly reduce the number of village animals killed in the effort to remove ferals and prevent exposure to the concentrated poison by children.

Eradication of feral dogs only treats a symptom of a more widespread problem--the uncontrolled recruitment of domestic animals into feral populations. The control of reproduction in domestic dogs, combined with an awareness by dog owners of the consequences of the escape, release, or abandonment of these animals, is necessary to limit the growth of feral populations. These three aspects of feral animal control should ideally be carried out simultaneously and continued on a regular basis. Careful monitoring of regions where feral dogs are known to be active and the repeated censusing of domestic populations to control the number and choice of reproductive males is paramount in the long-term success of such a program.

ACKNOWLEDGMENTS

This project was conducted under the auspices of the Galápagos National Park Service and the Charles Darwin Research Station. Funding for the eradication was provided by the Frankfurt Zoological Society. I wish to express my gratitude to Miguel Cifuentes, Fausto Cepeda, Friedemann Köster, and the employees of the National Park Service and Charles Darwin Station, without whose conscientious effort the measure of success realized by the program would not have been achieved. These included; Alan Moore, Oswaldo Chappy, Luis and Roberto Torres, Humberto Andrade and José Paucar. Thanks also to the Smithsonian Institution and the Belgian Research Table of the Charles Darwin Foundation, who subsidized the scientific aspects of the eradication.

LITERATURE CITED

ANONYMOUS. 1976. Tortoises, iguanas and the menace of feral dogs. Noticias de Galápagos 25:1-2.

ATZERT, S. P. 1971. A review of sodium monofluoroacetate (compound 1080): Its properties, toxicology, and use in predator and rodent control. Special Scientific Report - Wildlife No. 146. U.S.D.I./U.S.F.W.S.

BARNETT, B. D. 1985. Chemical vasectomy of domestic dogs in the Galápagos Islands. Theriogenology 23:499-509.

BARNETT, B. D., and R. L. RUDD. 1983. Feral dogs of the Galápagos Islands: Impact and control. Int. J. Stud. An. Prob. 4:44-58.

BEEBE, W. 1923. Williams Galápagos Expedition. Zoologica 5:3-22.

_________. 1924. Voyage of the Arcturus. Putnam, London, U.K.

BOERSMA, D. 1974. The Galápagos penguin: A study of adaptations for life in an unpredictable environment. Ph.D. dissertation, Ohio State University, Columbus.

BRUSS, M. L., J. S. GREEN, and J. N. STELLFLUG. 1983. Electroejaculation of the coyote. Theriogenology 20:53-59.

DARWIN, C. 1845. A Naturalist's Voyage Around the World. John Murray, London. p. 405.

GIL, J. L., and H. D. HAFS. 1971. Analysis of repeated measurements of animals. J. Anim. Sci. 33: 331-336.
HARCOURT, S. 1981. Distribution and number of penguins in Galápagos in 1980. Charles Darwin Research Station Annual Report, Santa Cruz, Galápagos.
HELLER, E. 1903. Papers from the Hopkins Stanford Expedition, 1898-1899. XIV Reptiles. Proc. Wash. Acad. Sci. 5:39-98.
KASTDALEN, A. 1982. Changes in the biology of Santa Cruz 1935-1965. Noticias de Galápagos 35:7-12.
KRUUK, H. 1979. Ecology and control of feral dogs in the Galápagos. Unpublished report, Institute of Terrestrial Ecology, Banchory, Scotland.
_______, and H. SNELL. 1981. Prey selection by feral dogs from a population of marine iguanas (Amblyrhynchus cristatus). J. Appl. Ecol. 18:197-204.
LAURIE, A. 1981. Population dynamics and social organization of marine iguanas on Galápagos: Progress report No. 1. Charles Darwin Research Station, Santa Cruz, Galápagos.
MARTINEZ, N. 1915. Impresiones de un Viaje. Talleres de Policia Nacional, Quito, Ecuador.
McGIRR, J. L., and D. S. PAPWORTH. 1955. The toxicity of Rodenticides I: Sodium fluoroacetate, antu and warfarin. The Veterinary Record 67:14-131.
McILROY, J. C. 1981. The sensitivity of Australian animals to 1080 poison I: Intraspecific variation and factors affecting acute toxicity. Aust. Wildl. Res. 8:369-383.
_______. 1982. The sensitivity of Australian animals to 1080 poison IV: Native and introduced rodents. Aust. Wildl. Res. 9:505-517.
MELVILLE, H. 1856. The Encantadas, In: Four Short Novels. Bantam Paperbacks, New York, N.Y.
MOORE, A. 1981. Special project for the eradication of feral dogs. Unpublished report. Galápagos National Park Service, Santa Cruz, Galápagos.
NAVEDA, B. H. 1950. Galápagos a la Vista. El Commercio, Quito, Ecuador.
OLIVER, A. J., and D. R. KING. 1983. The influence of ambient temperatures upon the susceptibility of mammals to compound 1080. Unpublished manuscript.
PINEDA, M. H. 1978. Chemical vasectomy in dogs. Canine Practice 5:34-36.
PINEDA, M. H., and D. I. HEPLER. 1981. Chemical vasectomy in dogs: A long-term study. Theriogenology 16:1-11.
RAMMELL, C. G., and P. A. FLEMING. 1978. Compound 1080: Properties and use of sodium monofluoroacetate in New Zealand. Animal Health Division, Ministry of Agriculture and Fisheries, Wellington, New Zealand.
ROBINSON, W. A. 1936. Voyage to the Galápagos. Harcourt, Brace and World, New York, N.Y.
SALVIN, O. 1876. On the avifauna of the Galápagos Archipelago. Trans. Zool. Soc. London 9:447-510.
SLEVIN, J. R. 1931. Log of the schooner "Academy". Calif. Acad. Sci. 17:1-162.
_______. 1959. The Galápagos Islands: A history of their exploration. Calif. Acad. Sci. 25:1-150.
SNEDECOR, G. W., and W. G. COCHRAN. 1967. Statistical Methods (6th Ed.). The Iowa State University Press, Ames. pp. 369-375.
THORNTON, I. 1971. Darwin's Islands: A Natural History of the Galápagos. Natural History Press, New York, N.Y.
WADE, D. A. 1976. Standard guidelines for the use and development of sodium monofluoroacetate (compound 1080) as a predacide. In: Test Methods for Vertebrate Pest Control and Management Materials (W. B. Jackson and R. E. Marsh, Eds.). ASTM Technical Publication 625:157-170.