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FERAL CATS ON JARVIS ISLAND: THEIR EFFECTS AND THEIR ERADICATION

BY

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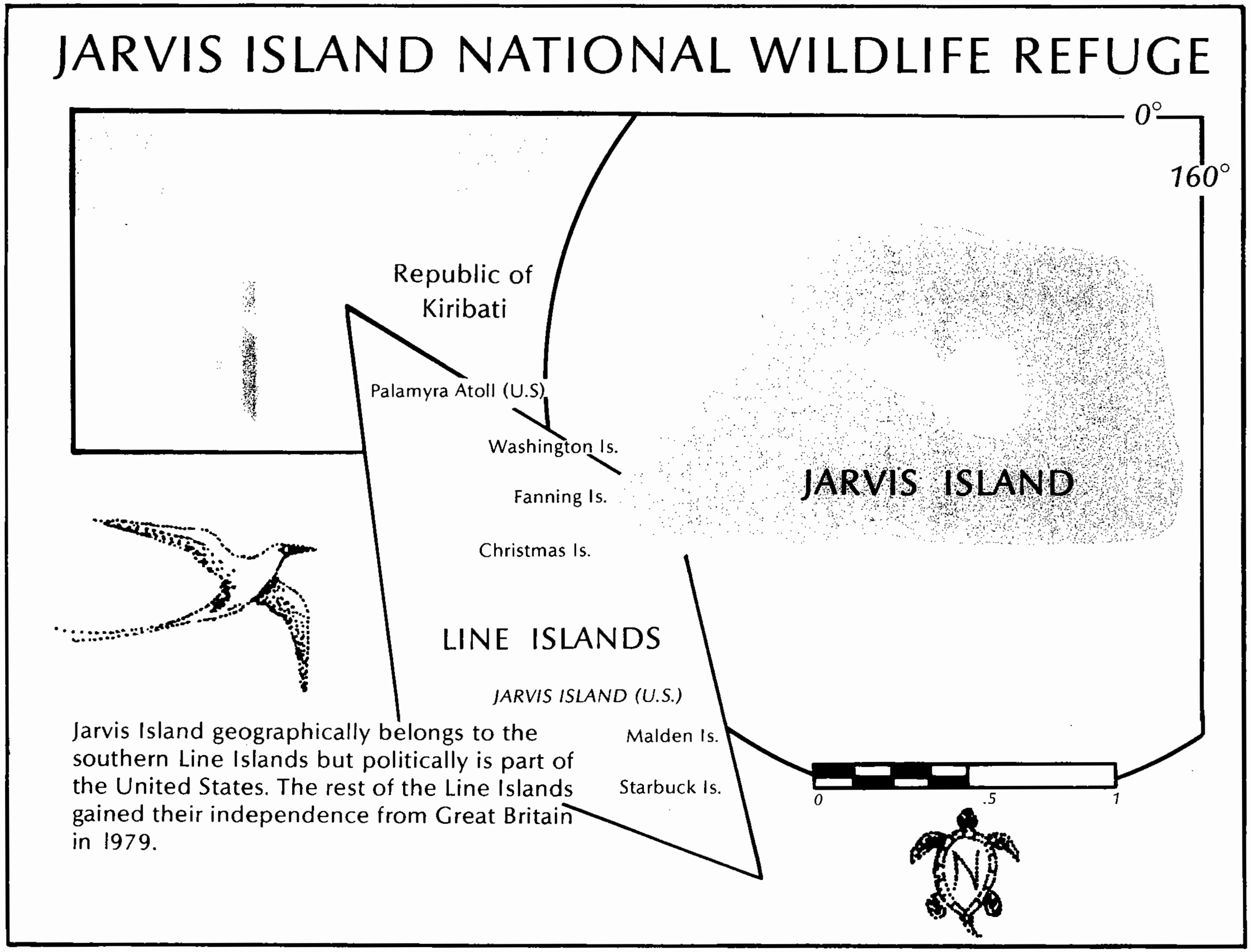

FIGURE I

LOCATION OF JARVIS ISLAND

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FERAL CATS ON JARVIS ISLAND: THEIR EFFECTS AND THEIR ERADICATION

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MARK J. RAUZON*

INTRODUCTION

Island ecosystems have proven to be particularly sensitive to human disturbances (Bourne 1975; Byrne 1980; Jarvis 1979). This was first noted by Charles Darwin in the explanation of his theory of natural selection (Byrne 1980). Since then, qualities of insular species have been examined by various authors in an attempt to understand the basis for island vulnerability.

Within island environments, there is generally less competition and predation than there is in corresponding continental habitats (Jarvis 1979). Introduced species are often competitively superior to insular species. However, the success of introduced species on oceanic islands can be attributed, in part, to human disturbance. The initial advantage of introduced species is their ability to withstand the types of disturbances associated with man (Egler 1942; Mueller-Dombois and Spatz 1972).

Of all the environmental changes caused by introduced species, predation has one of the most immediate effects on indigenous populations. Specifically, the feral cat (Felis catus) has played a major role in the eradication of native birds on islands. In New Zealand alone, these predators are implicated in the extinction of at least 6 endemic species and over 70 localized subspecies (Merton 1978).

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Research on Marion Island, a sub-Antarctic possession of South Africa, illustrates the potential magnitude of cat predation. By calculating the caloric needs of cats in all developmental stages and the caloric content of prey species, van Aarde (1980) was able to determine that 200 petrel-sized birds were eaten per cat per year. At least 455,119 birds had to be consumed to provide energy for the 2137 cats. Based on scat analysis of 375 cats on Macquarie Island, the yearly total of prey eaten are 56,000 rabbits (Oryctolagus cuniculus), 47,000 Antarctic prion (Pachyptila desolata) and 11,000 white-headed petrels (Pterodroma lessonii) (Jones 1977). Cats in the Kerguelen Archipelago probably kill about 1.2 million birds every year (Pascal 1980).

Returning a disrupted ecosystem to a condition more closely resembling the original state requires the complete removal of introduced species, especially predators. Even so, unanticipated results can occur. Attempts to eradicate rats which were endangering the Bermuda petrel (Pterodroma cahow) resulted in an increase of tropicbirds (Phaethon sp.) which colonized burrow nest sites formerly used by petrels. This problem was solved by fitting the burrows with baffles to exclude tropicbirds (Murphy 1964).

Eradicating introduced animals, even from relatively small islands, is a difficult and exacting task. This is particularly true in dealing with carnivores, which are capable of ". . . learned behavioral responses" (Beck 1975). Feral cats were eliminated from 8 islands in New Zealand. The complete removal of cats from Little Barrier Island spanned 4 years and involved 128 people and 3880 man-days (Veitch pers. comm.). A partial reduction of cats from Marion Island, South Africa, was produced by the introduction of feline panleucopenia virus followed by mechanical control efforts (van Aarde pers. comm.). I report here on the tentative eradication of feral cats from Jarvis Island, central Pacific Ocean.

JARVIS ISLAND

Jarvis Island (0^{o} 22'S, 160^{o} 01'W) is a remote, emergent atoll located approximately 1300 miles south of Hawaii between the Line and Phoenix Island groups (Figure 1). The island is about 25 miles south of the equator and 200 miles southwest of the nearest island, Christmas Island, Kiribati. It consists of 1024 acres (about 1.6 square miles) of coral rubble, phosphatic guano and organic detritus (Bryan 1974; Hutchinson 1950). The desert-like climate is characteristic of atolls in the Equatorial Dry Zone which is bordered roughly by 5^{o} latitude north and south. Slightly south of the equator and east of 180^{o} meridian lies the minimum rainfall region which includes Jarvis (Taylor 1973). This scantily vegetated island is highly reflective of strong solar radiation which retards precipitation over the island even when rain is falling over the surrounding ocean (Christophersen 1927). Only 30 inches of rain fell during the five-year period from 1975 to 1980. A remote automatic weather station was operated for about 3-1/2 years during that time (Vitousek, Kilonsky and Leslie 1980). To the north of the minimum rainfall zone, Christmas Island receives about 30 inches of rain per year.

The scarce vegetation is typical of strand communities of the tropical Pacific and consists of *Boerhaavia diffusa*, *Portulaca lutea*, *Sesuvium portulacastrum*, *Sida fallax*, *Tribulus cistoides*, *Lepturus repens*, *Eragrostis whitneyi* and *Abutilon indicum* (Christophersen 1927). The location and areal cover of major plant communities is shown in Figure 2. A similar map was reproduced by E. H. Bryan in 1942 and comparison between the 2 maps (Figure 3) indicate few changes except in the degree of *Tribulus* cover, a phenomenon which appears to be seasonal (Bryan 1942).

The highest point of the island is the northwest beach crest which is approximately 25 feet above mean sea level. The topography indicates that Jarvis Island was once a horseshoe shaped atoll with a lagoon in the center. As the lagoon drained and filled, extensive beds of gypsum were formed (Hague 1862 in Hutchinson 1950; Jewell 1961). Continual deposition of seabird excreta created a valuable deposit of phosphatic guano.

Jarvis Island was discovered by Captain Brown of the British ship ELIZA FRANCIS on 21 August 1821. Various ships visited this island, also known at the time as Jervis or Bunker, before 1856 when it was claimed by the American Guano Company and the United States Guano company under the U.S. Guano Act of 1856 which allowed ship captains to claim sovereignty over unoccupied islands. The U.S. government claimed that mere discovery did not give final title if not followed immediately by reasonable occupation. In February 1858, C. H. Judd took 23 Hawaiian laborers to begin mining guano (Judd 1960). Excavation of phosphatic guano lasted until 1879 (Bryan 1974). Initial estimates based on the vast numbers of seabirds present in 1856 predicted that 7 million tons of guano were available. However, log reports from commercial guano vessels indicate it was unlikely that the output exceeded 12,000 tons annually. By the termination of the lease in 1879, approximately 300,000 tons were removed from Jarvis Island making it one of the richest deposits in the Central Pacific (Hutchinson 1950). The ownership of Jarvis was contested when Great Britain annexed the island in 1889 and leased the deposits to the Pacific Phosphate Company of London and Melbourne. Because so little high quality guano remained, the lease was allowed to expire (Bryan 1974). Today, rows of low-grade spoil remain in 3 to 7 foot walls in the interior of the island providing dens for cats.

The value of Jarvis and other equatorial island possessions grew as trans-Pacific aviation became a reality. In 1935, Jarvis, Howland and Baker Islands were colonized with Hawaiian high school graduates. This action was followed by the Presidential Order 13.5 in 1936 re-establishing the claim to the islands as American territory (Bryan 1974). Great Britain then relinquished its claims (Leff 1940). The islands have since been administrated by the Department of the Interior and are now part of the Hawaiian and Pacific Islands National Wildlife Refuge system directly administered by the U.S. Fish and Wildlife Service in Honolulu, Hawaii.

Human occupation of Jarvis Island created changes in the simple ecosystem. Goats, rats, cats, mice and introduced plants like _Abutilon indicum_ undoubtedly affected the native ecosystem (Bryan 1974; Christophersen 1927; Judd 1960). In 1885, no birds were seen during a survey in October-November. One cat was observed "in possession of a house" (MacFarlane 1887). The Whippoorwill Expedition of 1924 found many mice and seabirds but no cats (Gregory, 1925).

CATS ON JARVIS ISLAND

By 1935, goats and cats had been extirpated but Polynesian rats (_Rattus exulans_) were still abundant. "What we call 'field mice' [small Polynesian rats] by the dozen crawl over the beds during the night and sometimes get caught between the blankets." (Bryan 1974). If cats had become established in 1885, rats would not have been so conspicuous. The Hawaiian colonists were required to note relevant biological observations (Bryan 1974). The presence of cats would not have escaped their notice. However, cats are mentioned in the correspondence surrounding the death of Karl Kalawai on October 1938. Kalawai's contemporaries were required to write their version of his death from appendicitis. In one letter, it was noted that the pet cat and dog were doing fine (Bryan 1974). It may be that the colonists brought cats, against orders, to prey on the disturbing number of rats. The cats may have escaped the confines of the camp and have become feral. King (1973) outlines the settlement of Jarvis and states that the settlers left cats when they abandoned the island.

During the International Geophysical Year 1957-58, the island was manned as a research station with scientists from Scripps Institute of Oceanography (King 1973). One scientist reported killing several hundred cats during his stay (R. Clapp pers. comm.). The Pacific Ocean Biological Survey Program (POBSP) visited Jarvis in 1964 and 1965 and they killed over 200 cats (King 1973). POBSP visits in 1967 and 1968 located only 9 cats in 2 days (King 1973). A visit in 1973 by the U.S. Bureau of Sport Fisheries, now the U.S. Fish and Wildlife Service, sighted at least 14 cats (Kridler 1973). Giezentanner (1976) reported killing 12 cats and sighting 50 more on 2 surveys around the island in 1976. In 1977, 102 cats were shot and 50 to 75 remained alive. In 1978, 160 cats were shot, most of them kittens (Forsell 1978). These data suggest the carrying capacity is less than 200 cats.

Surveys conducted opportunistically by the POBSP and during subsequent eradication efforts have identified and partially defined the extent of cat predation. Rats were formerly abundant on Jarvis but were probably extirpated by cats (King 1973). Mice (Mus musculus) persist in varying numbers. The POBSP noted the largest populations of birds over 4 years from 1963 to 1966 (Table 1). Three species of birds continue to breed in substantial numbers. Masked boobies (Sula dactylatra) and red-tailed tropicbirds (Phaethon rubricauda) are relatively large birds capable of defending themselves and their young. Sooty terns (Sterna fuscata) breed in very large numbers and inundate the cat population with more food than it can consume, then depart en masse. Nevertheless, the cats' predatory effects are significant. On nearby Starbuck Island, a cat population about the same size as that of Jarvis killed about 1000 birds a night (King 1973). Subsequent bird surveys have not been as comprehensive as the POBSP work which makes comparisons difficult. However, gross changes are apparent. In spite of annual and seasonal variation, the most obvious trend appeared to be a precipitious decline to the point of extirpation of the red-footed booby (S. sula) and the frigatebirds (Fregata sp.). Only roosting birds were seen in 1982-83 though derelict nests were found. Small ground-nesting birds were absent. Surveys in November 1983 indicate that predation has ceased and may offer proof that cats have been eliminated.

METHODS AND MATERIALS

From June 14 to 27, 1982, a study of the ecology and behavior of the cats was undertaken by David Woodside of the U.S. Fish and Wildlife

Service (FWS) and myself. Radio telemetry was used to determine home range and to test the efficacy of feline panleucopenia virus as a possible control agent. From June 27 to July 10, 1982, eradication techniques were implemented while additional biological observations were made. Attempts were made from October 28 to November 3, 1982, by Woodside, Steven Fairaizl (FWS) and Utimawa Bukaireiti of the Christmas Island Wildlife Conservation Unit (CIWCU) to complete the eradication work using recommendations garnered from the first trip. From March 3 to 9, 1983, Woodside and Katino Teebaki (CIWCU) attempted to remove the final cat(s) from Jarvis Island. Cameron B. Kepler (FWS) searched for cats from November 6 to 10, 1983, without sighting any. His seabird observations indicate that cat predation has ceased and that cats may be absent from Jarvis Island.

RADIO TELEMETRY

Cats were captured using TOMAHAWK live traps set nightly with various baits. Traps were checked early each morning to avoid subjecting the animals to heat stress. When a cat was to be collared with a radio transmitter, it was removed from the trap by placing a burlap bag over one end. The trapdoor was opened and the cat was directed into the bag. After the bag was tied shut, it was weighed using a 5 kg PESOLA spring scale. The bag weight was subtracted to give the net weight of the cat. The bag was carefully opened and the cat's head positioned at the entrance of the bag. The head and neck were exposed while the body continued to be restrained. While the head was held in a gloved hand, the neck was fitted with a radio transmitter collar. The collar was measured and cut to the appropriate size allowing the cat adequate room to swallow. The ends of the collar were bolted and glued together. The exposed metal end of the collar was taped and covered with heat-shrink plastic tubing to prevent any moisture from interfering with radio transmission.

Seven cats were fitted with radio transmitters of distinct frequencies for individual discrimination. AVM radio transmitters were selected for their range of frequency within the assigned U.S. Fish and Wildlife Service bands (164.467 to 164.709 megahertz) as well as their 3-month battery life. The collar weighed about 25 g which is the maximum size a cat can carry without interfering with its ability to carry out normal behavior. The transmission could be received over a 3 km distance or line of sight. Complimentary receivers (AVM) powered by 8 AA DURACELL batteries were used in conjunction with YAGI 3-tined antennaes compatible with the selected frequencies.

Radio checks were conducted twice a week by scanning the occupied channels. Compass bearings were taken of the maximum signal strength determined by standard pattern sweeps of the antenna (Cochran and Lord 1963). This single bearing technique sufficed when a general position was sought. Fixes were taken from 1 or 2 stations at known map locations and then plotted to determine a more exact position (Figure

4). However, some sources of bias and sampling error in this method of triangulation were sufficient to justify the more time consuming process of homing (Springer 1979). Homing was necessary to locate the den sites of inoculated cats. This technique is to follow the direction of the maximum signal strength as it audibly increases. By intermittently increasing the interference (the 'squelch' knob) as the signal audibly increased, we were able to hear nuances in the strength of the signal and hence, determine it directionality (Cochran and Lord 1963).

The nature of the radio signal indicated the activity of the cat. A signal that varies in strength indicates an active animal that is moving its head. A steady signal indicates a recumbent animal. The surrounding environment affected the nature of the signal as well. Dense coral slabs interfered with the signal to present a 'muffled' sound. Likewise, transmission around metal objects gave a 'bounce' which confused directionality.

FELINE PANLEUCOPENIA

Five cats fitted with radio transmitters were given an oral dose of 0.5 cc feline panleucopenia virus (FPLV) and released. Two cats were collared and released unexposed to FPLV as control animals. An additional 26 cats were inoculated, 19 of these were marked with spray paint and released (Table 2). Data from bi-weekly fixes were used to determine the areas to which FPLV might spread as well as to define home range, den site affinity and movement. Significant movement hastened the spread of the contagion and justified inoculating fewer animals.

Poole (1972) has shown that a modified live panleucopenia virus is stable at 37^{o}C when stored in the medium in which it was produced for up to 5 months. Based on in vitro stability of the virus when stored at room temperature, we felt that the virus could retain virulence when stored without refrigeration at Jarvis Island. Since we were unable to hold cats in captivity to determine the dosage and potency of the virus, we used the radio-collared cats to provide these data.

BAITS

Bait attraction studies were conducted concurrently with live trapping to determine the most effective baits for this and future control efforts (Table 3). The first baits were chosen for their intrinsic attractiveness to cats. Several species of reef fish were initially tried. Gray mullet (Mugil cephalus), 'aholehole (Kuhlia sandvicensis) and manini (Acanthurus triostegus) were used as baits for 80 trap-nights. The fish were halved and partially scaled to enhance their attractiveness to cats.

In order to determine if traps were affecting the attractiveness of baits, a series of bait trials was established. Each evening for one week, 2 fish baits were set at least 10 feet from each other at 9 designated bait stations. Any evidence of visitation or fish consumption was recorded. Canned cat food (CALCAN; 'simmered supper', liver and fish) and canned sardines were also tested. A series of 6 open cans were placed at bait stations away from the traps. Station areas were cleared to detect cat footprints. Tincture of catnip was used as a lure in spite of previous low success rates (van Aarde pers. comm.). Twenty drops of catnip were placed on a small cloth bag stuffed with grass (Lepturus repens) to aid fragrance dispersal. Finally, the attactiveness of freshly killed sooty terns which were cut in half and set at bait stations was determined. During the second trip, feline gland lure was used on steel and CONIBEAR 220 traps. This experimental lure was made from the testes and urine of male cats.

POISON

After 14 days had elapsed, chemical and mechanical control methods were initiated. Because the use of the effective predacide 1080 is banned on federal lands, 3 experimental compounds and 2 known toxicants were cage bioassayed in Hawaii in order to determine a suitable alternative (Fellows 1982). Based on these results, the compound N-(3-chloro-4-methylphenyl acetamide) or CAT was chosen for field testing. It was imperative that CAT hold no secondary poisoning potential for scavenging birds or invertebrates. A series of cage bioassay tests were conducted with 7 captive hermit crabs (Coenobita perlitus). Fifty grams of dry cat food was mixed with seawater and 90 mg of CAT. This yielded a toxicity of 0.18% Active Ingredient (AI). The crabs were held for 3 days in a shaded chicken wire cage and fed this mixture and water. The experiment was repeated with 3 groups of 6 crabs. The control group received 50 g of cat food and water. The second group received 50 g of moistened food with 90 mg (0.18% AI) of CAT. The third group received moistened food with 180 mg (0.25% AI) of CAT. All groups were held for 3 days and released. The control group was unmarked, the second group was spray-painted orange and the third was spray-painted blue.

Approximately 50 g of sooty tern flesh rubbed with 90 mg of CAT constituted the LD_{50} or lethal dose required to kill 50% of the cats upon first ingestion. Thirty pieces of freshly killed sooty tern were smeared with 50 mg of CAT and placed in open trays in the quarry area on June 27. Signs of visitation were noted the following morning. On July 10, the day prior to our departure, 20 pieces of sooty tern bait were placed in and around the burrows of wedge-tailed shearwater (Puffinus pacificus) which were also used by cats.

TRAPPING

In order to capture gun-shy cats, 2 other styles of traps were used. Steel or 'gin' traps designed to capture the cat by the foot were used in situations when the trap could be camouflaged. Lethal CONIBEAR 220 traps were set in den site entrances to trap cats as they entered or left.

To determine the density of house mice on Jarvis Island, a line of snap-traps baited with peanut butter was set in the quarry area within a microhabitat of Lepturus repens and around the camp at the north coast. The 3 traps at camp were caged inside chicken wire to exclude hermit crabs. An additional 17 were set without wire cages since hermit crabs are largely absent from the quarry.

Kepler (1984) attempted to census the house mouse population by counting mice on 5 transects covering an area of approximately 16,000 ft^2.

HUNTING

Hunting has played a major role in the eradication of cats from numerous islands in New Zealand (Veitch 1980) and South Africa (van Aarde 1980). Its effectiveness is enhanced when used in conjunction with a battery of other control measures (Beck 1975). Night hunting began on 27 June 1982 and continued until 10 July. Since cats are primarily nocturnal, headlamps powered with 2 D cell batteries were used to illuminate the horizon and create 'eyeshine,' a reflective response from the inner layer of the cornea of nocturnal animals. This is visible as a blue or orange glow from about 50 m away on dark nights. Ambient moonlight diluted the reflective response. On the second visit, which coincided with a full moon, more powerful spot lights were used. Night hunting was done with a Q-BEAM and SL-20 rechargable hand-held spotlights. The SL-20's were taped to the barrels of the guns to facilitate sightings. A REMINGTON 12 gauge shotgun, single barrel with a modified choke using No. 2-3 shot for ample pattern spread and stopping power, was used primarily at night. Cats were shot during the day with a 0.22 mm calibre rifle fitted with a 4 by 40 telescopic sight using long hollow point ammunition. Post-mortem data collected from each cat include weight, sex, color, reproductive condition (in females) and stomach contents (Table 4).

BIRD CENSUSES

A census of nesting birds was made to determine what effects the removal of predators would have on population numbers. Comparison with earlier POBSP data allowed population trends to be identified (Table

1). Estimates of nesting sooty terns were made by measuring four 10 meter square plots and counting all the enclosed eggs. Simple counts of masked and brown boobies (S. leucogaster), wedge-tailed shearwaters and red-tailed tropicbirds were also made in 1982. Other non-breeding birds were censused as they arrived. The population estimates represent maximum numbers. Kepler (1984) censused birds in November 1983 using a series of transects. His work will allow repeated comparisons on future expeditions.

RESULTS AND DISCUSSION

RADIO TELEMETRY

The results of the telemetry study indicate that the radio-collared cats remain in specific den sites during the hottest part of the day and become active at dusk (Figure 4). The principal feeding area on Jarvis Island was located along the south shore away from any known den sites. Panaman (1981) reports that within the home range, cats attempt to cover droppings but outside the home range, droppings remain exposed. Several high-density areas of cat droppings were found in the middle of the island well away from any suitable den site cover. It may be that the north shore cats cross the island to feed and while in transit, pause to mark these sites. No dropping sites were found in known home ranges of collared cats.

The home range was determined by plotting the fixes taken by homing and triangulation. Some positions taken by triangulation may be in slight error. Also some signals were not received during fixes. The female cats (nos. 3, 4, 7, 9) were consistently tracked to specific dens. Cat No. 3 used the periphery of the guano quarry as a home range (Figure 4). Cat No. 4, a lactating female with a small kitten, used the southern portion of the quarry. This area had dense Lepturus and loose ground for cover. Cat Nos. 7 and 9 inhabited the coral slabs of the north coast. There appeared to be considerable movement along this coast. No. 7 was also recorded in the quarry by a questionable fix. The home range area surrounding the den site is larger for males than for females (Macdonald and Apps 1978). The male cats (Nos. 6, 8, 11) were located in various den sites. Cats 6 and 8 were once recorded sharing the same den at the same time in the quarry area. Cat 8 was recorded mostly from the north east coast but was killed in the quarry accompanying cat No. 4.

It may be that the lack of suitable dens forced cats to share. One den in the quarry was occupied by at least 2 males, 2 females and one large kitten during the observation period. Although no cats were recorded near the southern sooty tern colony, it is clear from stomach analysis that the cats move freely across the island to feed on terns.

Veitch (1980) found cats on Little Barrier Island had a variable home range depending on the proximity of the feeding area.

FELINE PANLEUCOPENIA

We felt the spread of the contagion FPLV was likely because cats seemed to co-habit sites. Transmission of FPLV usually occurs by direct contact between the infected and the susceptible cats via saliva, feces, urine and fleas (Kahn 1978). In fully suspectible cats, i.e., those without active immunity, termination of the disease, either by death or by recovery is from one to 10 days (Veitch 1982). Death may occur at any stage after the rise in body temperature, however, it usually occurs after 2 to 4 days of manifest illness. The virus creates severe hemotological changes by destroying the blood-forming tissues. There is a gradual fall in the white blood cells, followed by dehydration. Recovery is characterized by a rise in white blood cells and the appearance of antibodies. It takes the animal several weeks to regain normal body weight but it will have acquired active immunity for up to 4 years (Gaud and Hallauer 1976; Veitch 1982). Feline panleucopenia is present in feral cat populations of most large areas. The disease tends to gradually build up to epidemic proportions and spread to all susceptible individuals before it dies out. Islands are usually too small to harbor reservoirs of the virus, so once it has passed through a population, it will die out. We believed the cats on Jarvis may have been exposed to the virus many years ago but were again susceptible.

The virus appears to have had a significant effect on the population. Cat No. 3, a female, died within 10 days of receiving an oral dose of FPLV. She exhibited the clinical symptoms of mucal discharge about the eyes and nose. She was located via telemetry at the periphery of the quarry appearing sluggish and listless. The next day she was found dead in the open grass. The remaining 4 radio-collared infected cats were allowed to live up to 18 days before it was necessary to kill them. No further expression of FPLV was noted. During the hunting phase, 10 out of the 19 marked and infected cats were shot. All appeared healthy with excess fat stores in the peritoneal cavity and displayed glossy coats and well-developed teeth. However, 9 of the 19 were not resighted. It may be that these cats died from the disease and went unnoticed. It is also possible that these cats were among those shot at night and not recognized because the marks rubbed off. The possibility that these cats represent additional FPLV mortality must be considered in light of the data presented by Scott, et al. (1970). He reports that about 50% of the challenged cats will expire. Van Aarde (pers comm) has used FPLV to reduce the cat population of Marion Island by 54% within 2 years of initial exposure. His most recent survey (May 1980) indicated a further 65% decrease with no indication of immunity build-up. At Jarvis Island, we felt that mortality would be above 50% since the xeric climate would hasten dehydration. The mean daytime temperature of

95°F may have affected the virulence of the virus in spite of Poole's (1972) suggestion that the virus could survive at 99°C. At best, we had a 41% mortality of marked cats (Table 2).

Veitch (1980) concluded that FPLV did not work well enough to justify the trapping effort needed to inoculate at least 5% of the population to spread the contagion. In areas with dense cover, it is very difficult to determine the extent of mortality necessary to justify its continued use in lieu of more conventional control methods.

BAITING AND TRAPPING

Baits are used either to lure cats into traps or to carry poison (Veitch 1982). Fresh fish is a readily available bait on islands so we began to trap cats using fresh reef fish (Table 3). In the 80 traps that were set, 11 cats were captured (14% success rate). Concurrently, 18 pieces of fish were set outside of traps to see if cats avoided the traps. Only 2 pieces (11%) appeared to have been visited by cats. Canned cat food and sardines were tried as bait in 12 traps but no cats were captured. Even at 18 bait stations outside of traps, there was no evidence of cat interest. Tincture of catnip was used in 4 traps also without success.

Sooty terns appear to be the most attractive bait judging from trapping results. Before hunting began, 64 traps were set with terns and 25 cats were captured (39%). After hunting, 40 traps were set and 4 cats were captured (10%). The relatively high success rate of 39% led us to choose terns as the main bait for trapping and poisoning efforts. Overnight, all baits became infested with Oedemerid beetles (Ananca bicolor) which greatly reduced their attractiveness. However, day-old sooty tern pieces still held some attraction. This was an unexpected lure since felids do not readily accept carrion as bait (Beck 1975). Two cats were captured with this bait and several others showed interest by pulling the feathers which protruded from the cage until the meat was in contact with the wire mesh. Some fresh baits were partially consumed in this manner. This learned behavior may indicate trap avoidance. Only 2 marked inoculated cats were recaptured, although unmarked inoculated cats may have been. Using all combined baits, 200 traps were set and 40 cats were captured (20%). It is instructive to compare the trapping effort at Little Barrier Island, a heavily forested and highly eroded island, with that at Jarvis. In 1977, 2637 traps were set and 26 cats were caught. In 1978, 37,332 traps were set and 73 cats were caught. In 1980, the last year of trapping, 32,615 traps were set and only 5 cats were caught (Veitch 1982).

Trapping success is a function of population size and the experience of the trappers. As animals become more scarce, the success in trapping declines at roughly an exponential rate. In order to trap experienced animals, we used 2 other styles of traps, leg-holds and

CONIBEARS. These traps would have had a higher success rate if used earlier in the eradication campaign. Since these traps were not baited, they were placed in areas that animals frequent, like denning sites or runways. Leg-hold traps were placed in entrances and along runways blocked with fencing which detoured the cat into the traps. During 49 trap-nights, one cat was caught (2%). CONIBEAR 220 traps are even more site specific since they must be supported externally. Seven traps were placed in the entrance to dens. Two cats were killed. Two red-tailed tropicbirds were caught and killed while exploring potential nest sites. These were the only cases of non-target vertebrate mortality.

During the October-November trip, feline gland lure was used in addition to various baits such as booby meat and cooked fish. In spite of the lure's previous success in mainland situations, no cats were caught. This is probably a result of very low population densities.

In attempting to estimate rodent population density, 46 snap-traps were set in the quarry. No mice were caught. In traps without a chicken wire enclosure, 4 land crabs were caught. Three traps were set at camp where mice were previously seen. Two were caught.

POISONING

Since hermit crabs are potential subjects for secondary poisoning by scavenging, a series of toxicity tests were initiated on 18 June with 7 crabs. The crabs received cat food mixed with 0.18% AI CAT. They were not observed eating the bait during the 3 day trial. They appeared listless and hung upside-down in the cage after repeated escape attempted failed. They were released and the food was exposed to free-roaming crabs who quickly consumed it. It appeared that the listless behavior was a response to captivity.

This experiment was repeated with 3 groups of 6 crabs. A portion of the poisoned bait was consumed by 2 groups. The crabs again appeared listless. One individual shed its shell and escaped through the wire mesh. The spray-painted crabs which had consumed bait with 0.18% and 0.25% AI CAT were released and subsequently resighted one week later along the beach. It appeared that these concentrations of CAT were not lethal to hermit crabs. These data are essential if aerial broadcasting of poisoned bait is considered as a future control method.

Thirty 50 g pieces of sooty tern were poisoned with 0.18% CAT (Table 3). The following morning, 15 pieces (50%) remained untouched. Five pieces (16%) were moved but not eaten. Nine pieces (30%) were partially eaten and one piece was wholly removed. Two days later, this test was repeated with 28 pieces. Seventeen (60%) were untouched. Two (7%) were moved but not eaten. Two were partially eaten and 7 (25%) were removed. The relatively high rate of consumption (33%) approaches the rate of trapping success using sooty terns. In addition, 28 pieces of poisoned bait were placed in and around shearwater burrows occupied by cats. The effect of the baits is unknown. No carcasses of poisoned cats were found. Veitch (1980) reports similar findings. At least 26,850 pieces of bait were placed on Little Barrier Island, but only 4 carcasses were found.

Fellows (1982) determined in test animals that the mortality rate was about 75% in cats that consumed at least 13 mg of CAT per kg of body weight. Assuming that only half of the 50 g bait (0.25% AI) was consumed, it would have delivered a lethal dose to the heaviest cat on Jarvis Island (Table 4). Death from CAT is due to renal failure (Palmore 1978). Like FPLV, it was hoped that the xeric climate might increase mortality. During the study, rainfall was sporadic, yet sufficient quantities collected in the shells of the giant clam (*Tridacna maxima*) to provide a constant supply.

HUNTING

The number of cats shot during the 1982 hunting period is plotted in Figure 5. The number of cats shot per day is plotted along the Y axis with the number of hours hunted per day. The number of hunting days is plotted along the X axis. The obvious trend is initially high mortality with a quick drop-off as hunting progresses. The number of hours hunted per day is the man-hour effort. As targets become fewer, man-hours to hit those few targets increases. The first 7 days of hunting yielded 1.97 cats per man-hour of hunting. The yield for the second week was only 0.19 cats per man-hour. The total yield for 110 man-hours of hunting was 105 cats or about one cat per hour of hunting from a population of about 44 cats per km^2.

Past eradication efforts on Jarvis Island have been brief though targets numerous. Thus a high rate of depletion was obtained by Forsell (1977, 1978). He shot 5 cats per man-hour in 1977 for a total of 102. He estimated that 50 to 75 cats remained alive. In 1978, he and a group of U.S. Coast Guardsmen shot 4 cats per man-hour to reach a total of 160. With the same manpower on Howland Island, the hunting kill was only 0.8 cats per man-hour in 1977 and 0.14 in 1978. The latter rate approximates that in our attempt to shoot the last Jarvis cats. On the October 1982 trip, Woodside spent over 100 hours to shoot two cats. In March 1983, over 100 hours were hunted without success. At least one cat was sighted (Woodside pers. comm.). In June 1983, an experienced hunter reported seeing no cats during 2 days of hunting (Austin pers. comm.). Kepler (1984) hunted for 35 hours over 4 days without seeing any sign of cats, i.e., eyeshine or predated birds.

Hunting on the Kerguelen Archipelago halved the maximum lifespan and lowered the population age as well as caused a disequilibrium in the sex ratio. Hunting reduced the geographical range of the cat population (Pascal 1980). On Marion Island, van Aarde (pers. comm.) reported; "Under sub-Antarctic conditions with population density of approximately 10 adult cats per km^2, a success rate of 2.5 hours per cat (0.4 cats per hour) was achieved. This efficiency decreased roughly exponentially with a decrease in population density." Both Marion and Jarvis Islands are relatively clear of vegetative cover so hunting can be used effectively. On the well-vegetated Little Barrier Island even hunting with dogs was futile.

BIOLOGICAL POPULATION CHARACTERISTICS

Hunting provided the opportunity to examine the biological characteristics of the Jarvis Island cat population as a whole (Tables 4 and 5). The color and sex of 108 cats were recorded. Black females were the most common phenotype (33%) followed by black males (25.5%). Black cats composed 58.5% and tabby cats composed 31.5% of the population. While live-trapping, we noted that black cats caught in traps and exposed to the morning sun appeared listless and frothy at the mouth, but lighter tabby cats showed no ill effects. The black cats possibly experience more heat stress from high solar radiation than the lighter tabby cats. Van Aarde (1980) hypothesized that dark coat color may have some advantage in the sub-Antarctic and that a strong founder effect is indicated by the absence of piebald spotting. On Jarvis, only 2.1% of the cats were piebald. On the Kerguelen Archipelago, the feral cat has kept the principal dark color characteristics of the domestic cat for over 20 years (Derenne 1976). Dark cats may be more successful nocturnal hunters than lighter ones.

Relatively small sample sizes prevent any conclusions from being drawn but some interesting trends are apparent. Overall, the sex ratio is roughly equivalent; 52% females, 48% males. This difference is not significant ($P \leq 0.5$). However, the gray cats show a highly significant ($P \geq 0.02$) sexual bias to males (9:1). Piebald cats were the least common phenotype represented by 2 males and one female. The other non-gray cats were at least 95% black.

The weights of 42 adult cats fell within the normal range for the common domestic cat (Scott 1972). Tabby males were on the average the heaviest but the heaviest individual was a black male. The weights of both sexes were heavier than those reported from Raoul and Little Barrier Islands in New Zealand and lighter than those from Herekopare and the sub-Antarctic Macquarie Island (Veitch 1982, Jones 1977).

DIET

Of the 54 cat stomachs examined, 32 (59%) contained flesh and feathers of sooty tern adults and embryos as well as eggs. A subcolony of terns near the main colony was heavily predated. Small teeth marks on eggs indicated that cats fed on them. The colony was later deserted en masse. Although terns are known to desert colonies, especially in vulnerable peripherial areas, it would appear that predation is an added pressure to desert (Ashmole 1963). Stonehouse (1962) found that cats on Ascension Island rarely ate sooty tern eggs however there are records of cats eating eggs of grey-faced petrels on Kerguelen Island and dominican gulls (Larus dominicanus) on Dassen Island, Southest Africa (Atkinson pers. comm.). Eggs may be a learned food source selected only by a few cats in some colonies.

Analysis of stomach contents showed that twenty one stomachs (38%) were empty. Since sooty terns settle on the ground after dark, the absence of food in these cats could indicate that night hunting had not yet begun. Also, during our hunting phase, the moon was full. Presumably, terns would be harder to catch on brightly lit nights and so the cats would be less successful. Since sooty terns are the primary food source, it is reasonable to assume that they limit the cat population. Stonehouse (1962) suggested that cats on Ascension Island are also limited by the nature of the tern breeding cycle. There is no shortage of food when terns arrive. When the breeding cycle is complete and they leave, cats are forced to survive on less easily obtained food.

One red-tailed tropicbird chick was identified in a cat stomach. A deserted masked booby chick was observed being stalked by a cat. It was later missing. The remaining 3% of the stomachs contained parts of crickets and cockroaches. Fitzpatrick (1979) found many species of invertebrates in cats which indicated a seasonal dependence on this food supply. One gecko was also identified in the remains. In spite of the abundance of reef fish, only one cat had fish in its stomach. These were probably prey items from a sooty tern which itself had subsequently been consumed. It may be that the abundant hermit and ghost crabs effectively compete for the carrion of the beach.

The last cat shot during the June/July trip had one mouse in its stomach. Several months later in October, one of the 2 cats shot had 5 mice in its stomach. During the March 1983 trip, mice were reported as very common in contrast to earlier trips. This increase in mice is almost certainly related to the decreased predation pressure. In November 1983, mice were conspicuous and possibly undergoing a population crash. A rough estimate of 36,000 mice on Jarvis represents an order of magnitude figure (Kepler 1984). During the Whippoorwill Expedition of 1924, mice were abundant (Gregory 1925). In 1935, mice were still abundant (Bryan 1974). In quoting the journals of the colonists, Bryan inserted in parenthesis that mice were Polynesian rats; "What we call 'field mice' [small Polynesian rats] by the dozen crawl . . ." (Bryan 1974). If this were true, then the introduced cats eliminated the rats but not the mice. However, it may be that the mice eliminated the rats since evidence from Stewart Island, New Zealand, suggests that mice are able to exclude ecologically Polynesian rats from a grassland biome (Taylor 1975). In other tropical regions, Polynesian rats do co-exist with mice but Jarvis Island may be such a simple ecosystem that this is impossible (Storer 1962; Tomich 1970).

FECUNDITY

During the hunting phase, 5 kittens were shot. This represents a relatively low recruitment rate which may be influenced by the lack of a steady food supply prior to the arrival of sooty terns. During late May 1982, terns began to arrive. Their arrival may have stimulated the onset of oestrous as evidenced by the apparent increase in pregnancies and the number of kittens in-utero. Of the 26 females examined, 8 were pregnant. The average number of embryos was 3. The survival rate of kittens is unknown but at least 24 could have been born.

BIRD POPULATIONS

Four 10 m by 10 m quadrats within the sooty tern colony were censused. The mean density of eggs was 37 per 10 m^2. We then measured the roughly linear colony to determine the area and multiplied that area by the mean egg density to determine that 210,000 eggs or 444,000 nesting birds were present. We estimated that an additional third of the colony were nonbreeders. Near the western and eastern beaches were 2 more colonies (Figure 4). Approximately 500,000 additional birds were present bringing the estimated total population of sooty tern to over 1 million birds.

Stonehouse (1962) considers the predatory effects of even 100 cats to be considerable. If the cat population is about 120 on Jarvis Island, and each cat eats a bird a day for about 200 days; the average period a colony might be established, then the annual cumulative predation could approach 25,000 birds per year or about 2.5% of the total sooty tern population.

The masked booby colony is one of the largest in the Central Pacific Ocean. King (1973) estimated that 9000 individuals were present. Our estimates of breeding birds agree but are slightly less for nonbreeding birds (Table 1). This species is loud and aggressive and apparently suffers little cat predation. Likewise, the red-tailed tropicbird is well-defended. King (1973) recorded "large populations of both frigatebirds and all three boobies. . . ." In 1982, about 1550 lesser frigatebirds and 550 red-footed boobies roosted in the center of the island at night. These birds were not breeding on Jarvis in 1982 and may be considered victims of cat predation. One partially consumed booby was found in the quarry well away from the roost site. In addition, less than 50 brown boobies and 10 wedge-tailed shearwaters breed on Jarvis Island. Other petrels, shearwaters and small terns are absent. A wing of a white-throated storm-petrel (<u>Nesofregata</u>

albigularis) was found on Jarvis Island indicating that this species may still visit and be a potential colonist.

Kepler (1984) found increased numbers of birds present during his November 1983 surveys conducted at approximately the same time as in the previous year (Table 1). He found 4 lesser frigatebird colonies with chicks. The largest colony (286 pairs) was only 50 m east of the guano quarry where cats were common in 1982. Red-footed boobies were breeding in small numbers. Kepler found 2 colonies, one with 15 nests, the other with 7 nests. Over 800 roosting birds were counted at night. Four separate sooty tern colonies were found out of syncrony with each other. Kepler attributes this to the species recovery from the effects of the El Nino that began in August 1982 (Firing et al. 1983).

CONCLUSIONS

Jarvis Island is considered to be of outstanding importance for the abundance of its wildlife especially breeding seabirds. The elimination of feral cats will probably make Jarvis Island one of the largest seabird colonies in the central Pacific Ocean (King 1973). Currently, the island is administered as part of the U.S. National Wildlife Refuge System by the U.S. Fish and Wildlife Service. Beginning in 1973, the Service attempted to eradicate the Jarvis cats by using sporadic control measures. In 1981, a systemic analysis of available control options and a survey of the results from other cat eradication work was conducted. As a result of this preparation, we investigated the use of feline panleucopenia virus as a control agent. Research in other insular situations suggest this technique could be helpful in reducing a susceptible population by at least 50%. By determining the home ranges and movements of cats using radio telemetry, we were able gauge the potential spread of the virus through the population. Only one radio-collared cat was killed by the virus. Additional deaths may have occurred to marked cats that were not subsequently recovered. If so, then the total mortality via FPLV was, at best, 41% of the inoculated cats. Nevertheless, we judged this technique to be relatively ineffective in lieu of other control measures which allowed full accountability of mortality. Accountability is essential, especially in the case of Jarvis Island, when visits are infrequent and of short duration.

Poisoning was another indeterminate technique particularly because experimental compounds were used. The current controversy surrounding the use of compound 1080 on federal lands prevented us from obtaining this effective toxin. However, bioassays conducted in Hawaii and on Jarvis Island have indicated that CAT is an effective control agent for cats and does not hold any secondary toxic effects for scavenging invertebrates. Aerial baiting could be possible with this toxin.

The combination of hunting and trapping proved most useful in removing the majority of the cats from the island. However, the success of these methods is limited by the amount of manpower available. As targets become fewer, the effort must correspondingly increase if the last cats are to be shot or trapped. This effort can become very costly, time consuming and frustrating especially if time is limited. On Jarvis Island, the last 250 man-hours of hunting removed only 2 cats.

Trapping efficacy is also affected by the population density of animals. After one week of hunting, the capture rate decreased from 39% to 10% while using terns as bait. A variety of baits were tested to determine the most attractive. Familiar foods, i.e., terns and fish (to a lesser degree), attracted all the cats that were trapped. The use of feline gland lure was ineffective but might succeed when baits fail during periods of abundant prey. Steel leg-hold and CONIBEAR 220 traps were useful and could have caught more cats if used earlier in the eradication effort. They could be effective in removing the last cats provided ample time was available. It is essential to use all available methods over a reasonable period of time to provide a broad front of eradication techniques to remove the last wary cats.

The ability to account for the carcasses of cats afforded an opportunity to survey the phenotypic expression of an entire population. The observation that the majority of the population is black suggests some adaptation to the environment. In spite of the black cats' susceptibility to heat stress during the day, they may be less conspicuous than the other phenotype when hunting at night. All cats examined appeared healthy with sleek fur and adequate fat deposits. The weights of the cats fell within the normal range for the domestic house cats, and in fact were heavier than temperate climate cats from New Zealand.

Ecologically, Jarvis Island is severely changed. The miners who removed 300 thousand tons of guano initially altered the simple ecosystem with introduced goats, rats and mice. Yet seabirds were able to continue to utilized the island as a nesting ground until the introduction of cats. Cats allegedly extirpated the smaller nesting species which occur on similar tropical islands without predators. It was the purpose of this eradication effort to remove the cats in the hope that these species of seabirds, which are threatened by predators on many other islets through the Pacific, would return to colonize Jarvis Island. Future surveys will be needed to identify the extent of recolonization and to monitor the status of introduced species.

In attempting to rid the island of cats, we tried various established and novel techniques. In 1982, we removed about 120 cats but were not successful in complete eradication in spite of 6 weeks of effort involving 5 people. However, it appears that very few, if any, cats remain. The first major nesting effort by lesser frigatebirds in 2 years suggested that the cat population has either been eradicated or is very low and probably not breeding. If the population contains one pregnant female, the population could rebuild its numbers in a brief period. We are not safe in assuming complete eradication until 4 or 5 years have passed with no cat signs. The threat of future cat or rat introductions is always present so long as ships pass by the island. The remoteness of Jarvis Island makes protection efforts very difficult.

Habitat rehabilitation is the responsibility of agencies in charge of administering disturbed lands. In the end, it remains the duty of the U.S. Fish and Wildlife Service to monitor the effects of eradication on Jarvis Island. To return disturbed ecosystems to a more natural state is a difficult task. Yet, every effort must be made to erase the deleterious effects that animals introduced by man have wrought. It must be stressed that man was the initial source of the introduced cats on Jarvis Island. Thus, it is our responsibility to remove them so the island can once again become a predator-free colony for many species of tropical seabirds.

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TABLE 1

ESTIMATES OF BIRD POPULATIONS OF JARVIS ISLAND

BREEDING BIRDS	1963 - 1966	1976 Nov.	1977 Oct.	1978 Oct.	1982 Jul.	1983 Nov.
Masked Booby	9000/3000	4000	950	3365	7000/3000	7000/2720
Red-footed Booby	1000/- *	-/10	-/2	-/1	500/0	850/22
Brown Booby	-/-	-/-	-/-	/-/-	500/100	170/80
Red-tailed Tropicbird	-/-	-/-	-/-	-/-	-/3000	32/16
Frigatebird sp.	8000/-	-/85	-/1	-/40	1500/-	GR 400/0 LS 700/339
Sooty Tern					1,000,000/400,000	580,000/209,000
POSSIBLE BREEDING BIRDS						
Wedge-tailed Shearwater					100/-	20/-
Gray-backed Tern					10/-	2/-

Key: (Total Adults, Rounded/Breeding Pairs)

* (-/-) no data available
GR = Great frigatebird
LS = Lesser frigatebird

TABLE 1 (continued)

ESTIMATES OF BIRD POPULATIONS OF JARVIS ISLAND

NON-BREEDING BIRDS Flying/Breeding	1963 - 1966 Aug. Sep. Oct.	1976 Nov.	1977 Oct.	1978 Oct.	1982 Jul.	1982 Oct.	1983 Nov.
White-throated Storm-petrel					1/0		
Brown Noddy					1/0		1/0
Black Noddy					1/0		
Blue-gray Noddy					1/0		
White Tern					7/0		
Bristle-thighed Curlew					10/0		
Wandering Tattler					3/0		
Ruddy Turnstone					5/0		
American Golden Plover					7/0		

TABLE II

CAUSES OF MORTALITY OF
CATS ON JARVIS ISLAND

	METHODS	TOTAL	HEALTHY AFTER 18 DAYS	MAX. POSSIBLE FPLV DEATH	SHOT
TRAPPED	INOCULATED & MARKED	19	10	47%	10
	INOCULATED & COLLARED	5	4	20%	4
	INOCULATED & NOT MARKED	7	?	?	-
	MARKED & NOT INOCULATED	2	2	0%	2
	LIVE TRAPPED & SHOT	2			2
	TRAPPED IN LEG-HOLD	1			1
	TRAPPED IN CONIBEAR	2			2
NOT TRAPPED	SHOT ON 14 JUNE, 1982				7
	SHOT BETWEEN 27 JUNE & 10 JULY, 1982				87
	SHOT BETWEEN 28 OCT. & 3 NOV., 1982				2
TOTAL		38	16	41%	117

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TABLE III

BAITING AND TRAPPING SUCCESS

BAITS	TRAPNIGHT/CAPTURES		TOTAL BAITS/CONSUMED BAITS	
FRESH FISH	80/11	(14%)	18/2	(11%)
CANNED CATFOOD	12/0	(0%)		
CATNIP	4/0	(0%)		
SOOTY TERN				
Prehunt	64/25	(39%)		
Posthunt	40/4	(10%)		
With CAT	200/4	(20%)	58/19	(33%)

TABLE IV

WEIGHTS OF CATS GROUPED BY COAT COLOR

COAT COLOR	BLACK		TABBY		GRAY		BLACK & WHITE		ALL CATS
SEX WEIGHT (kg)	M	F	M	F	M	F	M	F	
MEAN	2.85	2.27	3.28	2.54	3.20	-	2.95	-	
NUMBER	12	12	7	9	1		1		
STANDARD DEVIATION	0.44	0.30	0.12	0.18					
VARIANCE	0.19	0.10	0.01	0.03					
RANGE									1.65 - 3.50 (N=42)
ALL FEMALES									1.65 - 2.75 (N=21)
ALL MALES									2.25 - 3.50 (N=21)

TABLE V

SEX AND COLOR RATIOS
OF JARVIS ISLAND CATS

COLOR	MALES	FEMALES	TOTAL
NUMBER / PERCENT			
BLACK	27 / 25	36 / 33	63 / 58
TABBY	14 / 13	17 / 16	31 / 29
GRAY	9 / 8	1 / 0.7	10 / 9
BLACK & WHITE	2 / 1.4	1 / 0.7	3 / 3
COLOR?	-	1 / 1	1 / 1
TOTAL	52 / 48	56 / 52	108 / 100

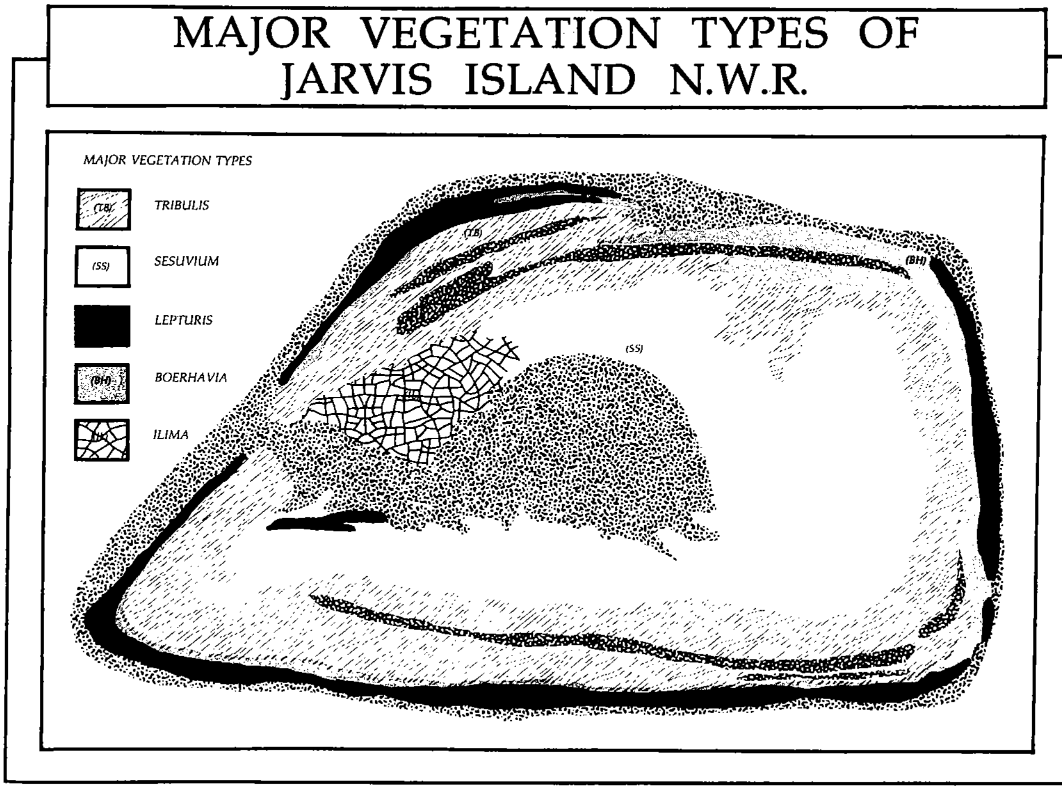

FIGURE II VEGETATION OF JARVIS ISLAND

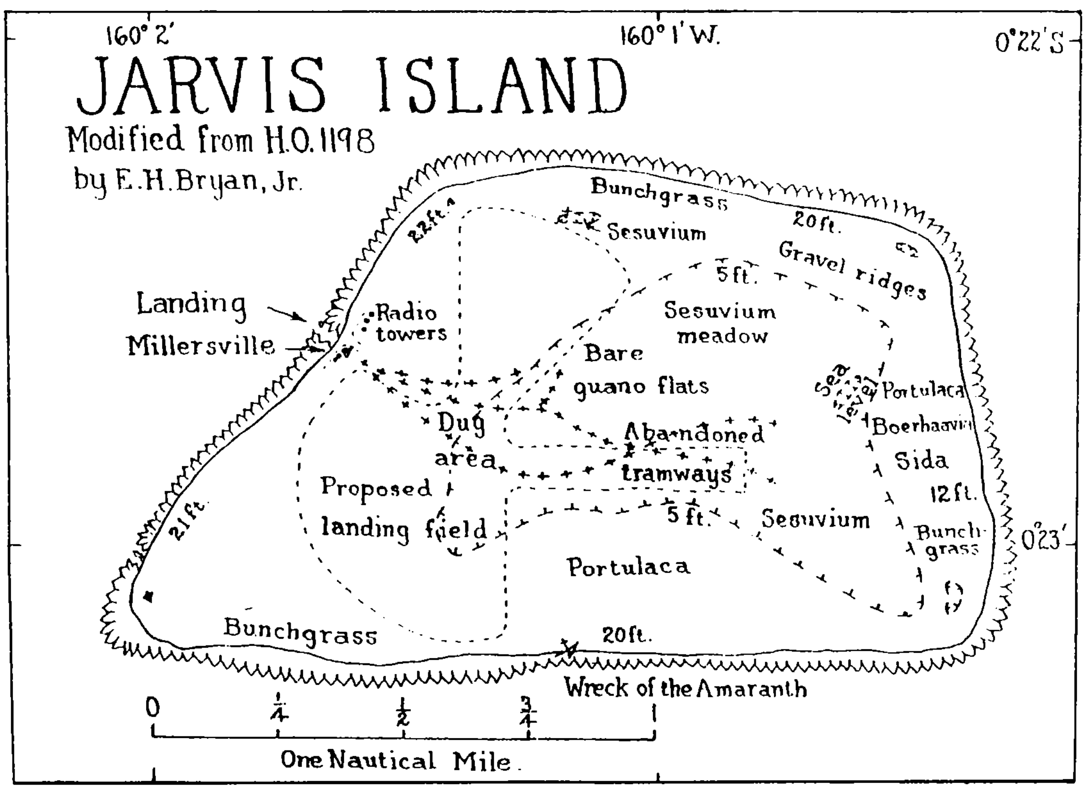

FIGURE III LANDMARKS OF JARVIS ISLAND (BRYAN 1942)

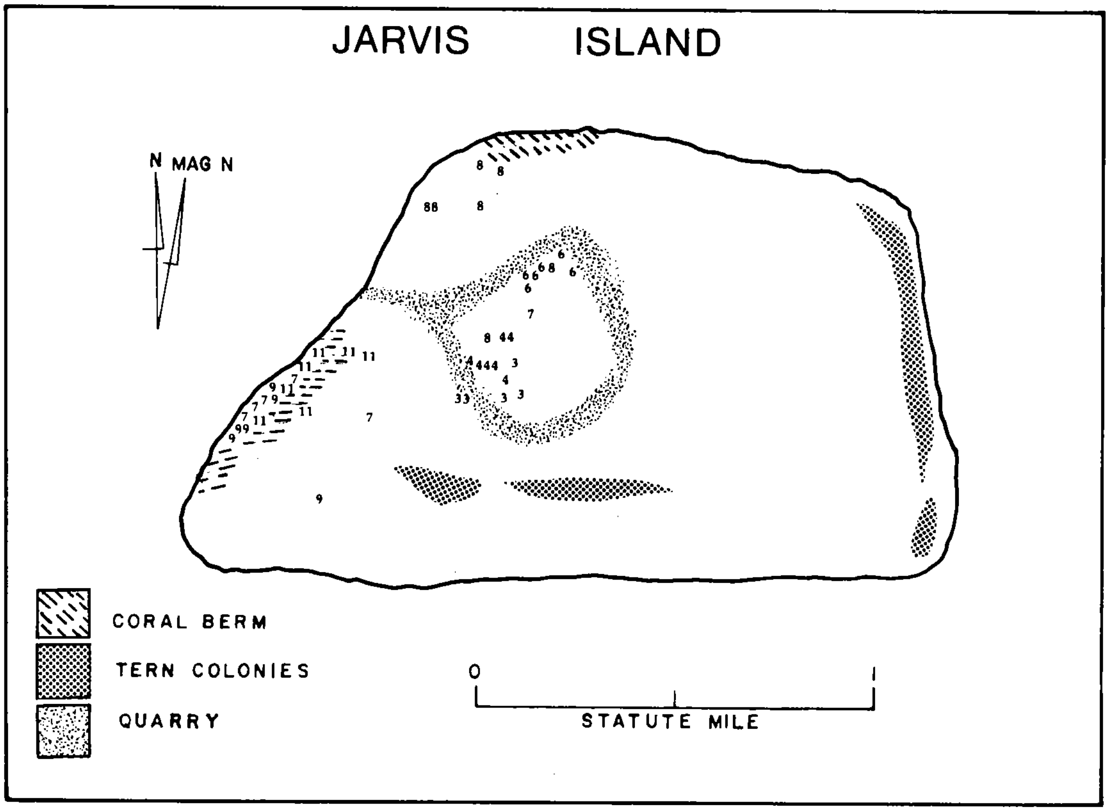

FIGURE IV

LOCATION OF COLLARED CATS DURING RADIO-TELEMETRY FIXES

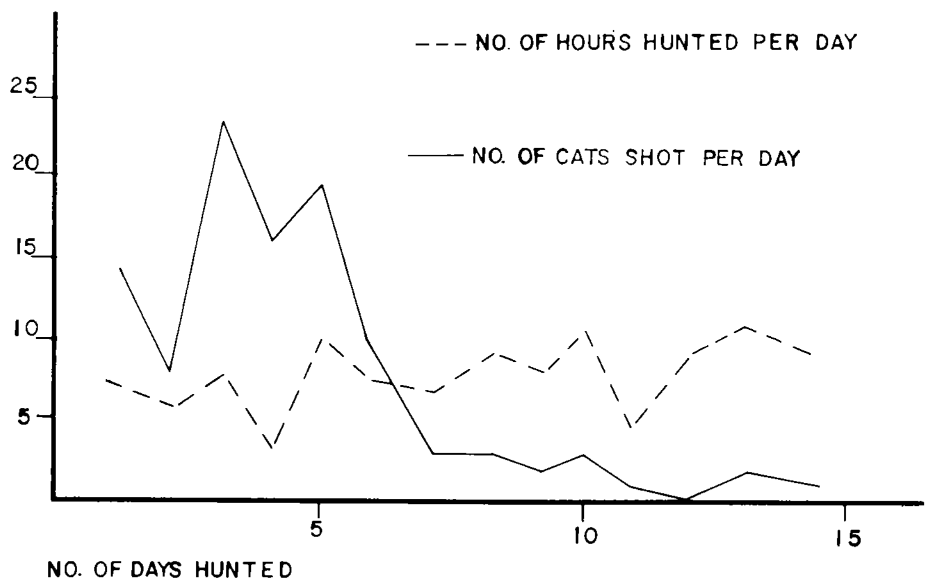

FIGURE V

AMOUNT OF TIME HUNTED AND THE NUMBER OF CATS SHOT