Gifts from 100 Christmases. Native and feral mammals of Christmas Island, Indian Ocean, after a century of human occupation

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Summary

Christmas Island, an Australian external territory, is an oceanic island of 135 km^2 about 360 km south of Java and 900 km north-east of the Cocos-Keeling Islands in the Indian Ocean. It is unusual in that it remained completely uninhabited by humans until 1888. Commercial exploitation of the phosphate deposits by surface mining began in 1895 and continued until 1987. Originally the island was covered with vegetation, principally tropical rainforest, but by 1987 about 25% of the land area had been cleared for phosphate extraction. Cleared land supports a very simple regrowth vegetation, dominated by exotic species, among which is the fruiting shrub/small tree, *Muntingia calabura*, which provides cover and a rich food resource for several native and exotic vertebrates.

At the time of settlement sixteen species of bird (four endemic), ten species of reptile (four endemic) and five mammal species occupied the island: two rats (*Rattus macleari* and *R. nativitatis*), an insectivorous bat (*Pipistrellus murrayi*), a flying-fox (*Pteropus melanotus*) and a shrew (*Crocidura attenuata*). The two rats and the insectivorous bat were endemics, restricted to the island, whereas the flying-fox and the shrew were species which occurred elsewhere in south-east Asia. This paper describes survey work carried out in 1984 and 1988 to determine the status and distribution of mammals on the island 100 years after settlement.

No trace has been seen of living animals of either of the endemic species of *Rattus* since about 1903 and they are considered to be extinct, but the status of the shrew remains uncertain. After none being seen for 87 years, one was found in late 1984 and another in early 1985. This study failed to locate any and the species is presumed to be extremely rare and it should be classified as endangered. Information on these species and their decline is summarised.

P. murrayi , an aerial insectivore, is common in all vegation types, except revegetated areas, but it forages over these. It is partially diurnal in the absence of diurnal avian predators. Unlike most vespertilionids it exhibits no sexual dimorphism. *P. melanotus* is also still common despite clearing and predation by humans and feral cats. The recent accidental introduction of the colubrid snake, *Lycodon aulicus*, may pose additional predation pressure on this species. Prior to human settlement it had no predators and, probably as a result of this, it is markedly diurnal. Camps are formed in a number of places around the coastline, but many animals live dispersed through the forest as singletons or in small groups. *P. melanotus* eats a wide variety of native fruits and flowers and is implicated in the seed dispersal and pollination of these species. It also feeds on

and disperses the seeds of *M. calabura*, an important colonising plant in disturbed areas.

Black rats, *Rattus rattus* and feral cats, *Felis catus* were found to be widespread on the island. Black rats reached their highest numbers on the coastal fringes and in regrowth vegetation and were rare in rainforest. Feral cats were similarly rare in rainforest and were found in greatest numbers in regrowth vegetation. House mice, *Mus musculus* , are restricted to regrowth areas.

Feral cats eat a wide range of vertebrate and invertebrate animals on Christmas Island, but flying foxes, Imperial pigeons, *Ducula*, and black rats together constitute over 83% of their food intake by weight. Over 50% of cats examined had eaten *Rattus* and 27% had eaten *Mus*. It is likely that the large numbers of cats observed in regrowth areas are related to the ease with which all four of these prey species may be caught there.

Direct control of cats, rats or mice on the island would be extremely difficult, and probably counterproductive, in view of the likelihood that the island biota, including these exotic species, has reached a new equilibrium. The only intervention which seems desirable in the long run is the rehabilitation of cleared areas.

Christmas Island National Park was declared in 1980. After several extensions it now covers over 60% of the island and there are plans to extend this further. A restricted mining operation in previously cleared areas has commenced, as has a programme to reestablish rainforest on former phosphate mining fields. Tourism is likely to play an increasingly greater role in the island's economy.

Introduction

Landform, climate and vegetation

Christmas Island (10° 25'S, 105° 40'E) is an oceanic island of Upper Eocene coralline limestone overlying volcanic andesite (basalt?). The island of 13,470 ha rises steeply from the surrrounding ocean and consists of a series of fringing limestone terraces, separated by rugged limestone cliffs and scree slopes, rising to a central plateau at about 200 m above sea level (Figure 1). It is a 'high' oceanic island reaching over 360 m above sea level. Most of the coastline is precipitous cliffs, except in a few places where the shoreline slopes more gradually and small beaches are present. Christmas Island is separated from the nearest neighbouring landmass, Java, by about 360 km and it is about 900 km from the Cocos-Keeling Islands.

The climate at 10° 25'S is monsoonal, with distinct wet and dry seasons, although temperatures vary little through the year (Table 1). The dry season is particularly pronounced because groundwater seeps away rapidly through the generally shallow soil and porous limestone. In the wet season the island comes under the influence of the north-west monsoon, while for the rest of the year the south-east trade winds dominate. Only one episode of winds of cyclonic severity has been recorded in 100 years - in March 1988. (Where is the evidence for these statements - Bureau of Meteorology holds no wind records) Surface water is, for the most part nonexistent in the dry season, except in three areas of small extent where the underlying impervious andesite/basalt lies close to the surface.

Because of the high rainfall the exposed limestone is characterised by extremely rough, eroded surfaces and limestone caves and fissures are common.

Recent descriptions of the vegetation and flora have been provided by Mitchell (1985) and Thompson (1992). Sixteen species of plants are endemic to Christmas Island (Thompson, 1992). Soil depth, because of its role in the supply of plant nutrients and water, is the primary determinant of vegetation distribution. This varies greatly from several metres on much of the central plateau to virtually none in areas where the limestone is exposed, either naturally or because of past mining operations.

Table 1. Mean monthly maximum and minimum temperatures and rainfall on Christmas Island over the period 1972-1989 (Commonwealth Bureau of Meteorology records).

Month	Max temp. (°C)	Min temp. (°C)	Rainfall (mm)
January	27.8	22.5	325
February	28.1	22.4	298
March	28.3	22.8	283
April	28.4	23.3	201
May	27.8	23.5	201
June	26.9	22.9	179
July	26.3	22.4	88
August	26.1	22.1	48
September	26.3	22.2	65
October	26.9	22.5	97
November	27.3	22.7	179
December	27.8	22.4	235

Sampling stratification in this study was based primarily on the vegetation associations described and mapped by Mitchell, who recognised seven main associations. (1) On areas where the soil depth is greatest a floristically fairly simple primary tropical rainforest is present. Major canopy trees are *Hernandia ovigera*, *Planchonella nitida*, *Syzigium operculatum* and *Inocarpus fagifer*. The first three of these are also frequent canopy emergents. *Barringtonia racemosa*, *Pisonia umbellifera*, *Pandanus elatus* and *Arenga listeri* are major undercanopy species. (2) Marginal rainforest in areas with shallower soil does not support *Hernandia*, but all the other primary rainforest species are present plus *Dysoxylum gaudichaudianum*, *Celtis timorensis*, *Terminalia catappa*, *Tristiropsis acutangula*, *Guettarda speciosa*, *Ficus microcarpa*, *Gyrocarpus americanus* and *Berrya cordifolia*. Many other species occur occasionally in the canopy and the understorey is similarly diverse. (3) The inland cliffs and scree slopes support a sparse community dominated by the shrubs *Ficus microcarpa* and *Pandanus christmatensis*. (4) A complex of open forest, scrubby forest and vine forest occurs in limited areas close to the coast, frequent species are *Allophylus cobbe*, *Hibiscus tiliaceus*, *Ochrosia acheringae*, *Acronychia trifoliata* and *Ficus microcarpa*, among others. (5) In other areas along the coastal fringe a complex of low closed woodland with *Pemphis acidula*, *Pandanus christmatensis* and *Macaranga tanarius* as commonly occurring species, and heath shrubland dominated by *Scaevola sericea* is present. (6) On the three areas where above ground freshwater seepage occurs a closed forest occurs, dominated variously by *Inocarpus fagifer*, *Syzigium operculatum* and *Bruguiera* spp. This vegetation association is of very limited extent. (7) In mined areas (which originally were almost exclusively primary and marginal rainforest) the soil has been almost totally removed. A depauperate shrubland now occurs on this land, dominated by *Leucaena leucocephala, Mimosa invasa, Macaranga tanarius, Muntingia calabura, Pipturus argenteus* and *Psidium guajava*. Stratification of the island for sampling in this study departed from Mitchell's strata in using only the *Scaevola* dominated shrubland, because it appeared to be the most productive biomass wise bird shit refuse etc ?

History of human occupation

The first recorded discovery of Christmas Island by Europeans was in 1643. A number of visits was made over the next two centuries by Dutch and British ships, but it was not investigated in any detail until the late 1850's, and it was not settled until 1888, when it was placed under the British flag. The object of this annexure was to exploit the rich phosphate deposits which had been found there in the previous year. Along with several other large islands in the region it seems never to have had an aboriginal human population (Gibson-Hill, 1949; Diamond, 1985).

The extremely rugged terrain of the island and its shortage of surface water, which perhaps were responsible for the lack of aboriginal inhabitants, also inhibited exploration away from the settlement at Flying Fish Cove. Mining with hand tools was slow, hard work and until about 1940 was restricted to a small area near the settlement. It was not until after World War II, when mechanisation was introduced to the mining operation, that large scale clearing of native vegetation began (Figure 2). In 1958 Christmas Island became an Australian external territory, which it remains. As phosphate deposits became depleted and world pricing structure changed, the mining operation gradually became uneconomic and eventually ceased at the end of 1987 (Williams and Macdonald, 1985; Neale, 1988; Stokes, 1988).

The human population of Christmas Island has varied considerably over the years since 1888. The maximum population size of 3,500 was reached during the 1970's, but since the 1987 cessation of mining it has stabilised to about 1000 individuals (Hugh??). A limited mining operation, restricted to previously cleared areas of the island, has recommenced, and a programme has been initiated to revegetate mined areas with revenue derived from the new mining operation. The government policy on the island is to promote tourism and a casino and tourist accommodation (?) have been built to this end.

Previous investigations of the mammal fauna

Five native species of mammals were originally found on Christmas Island: two rats, *Rattus macleari*, Thomas and *R. nativitatis*, Thomas; a shrew, *Crocidura fuliginosa trichura*, Dobson ; a flying fox, *Pteropus natalis*, Thomas (Thomas, 1887; 1888) and an insectivorous bat, *Pipistrellus murrayi*, Andrews (Andrews, 1900). Taxonomic changes have subsequently been made to the specific names of the shrew to *C. attenuata* (Jenkins, 1976) and the flying-fox to *P. melanotus* (Chasen, 1940). Both of the rats and the pipistrelle are still considered to be endemic to the island, whereas the flying-fox and the shrew are known to occur elsewhere in south-east Asia. (Jenkins, 1981; Honacki, et al, 1982; Hill and Harrison, 1987)

In 1897 when Andrews conducted his landmark investigation of the natural history of the island all five species of indigenous mammals were common, at least in the vicinity of the settlement at Flying-Fish Cove. The only species which appeared to be rather restricted in its distribution was *R. nativitatis* (Andrews, 1900). Eleven years later Andrews revisited Christmas Island and found that the situation had changed dramatically (Andrews, 1909). The two rats and the shrew had apparently become extinct, although the two bats were still common, and two introductions had become established; the black rat, *Rattus rattus* and the cat, *Felis catus*.

Andrews attributed the disappearance of the native rats to the introduction, along with the black rats, of a pathogen, which proved lethal to the immunologically naive native species. He advanced two lines of evidence to support the contention that disease rather than competition, or some other interaction with *R. rattus*, was responsible for the demise of the two native species: (1) that *R. rattus* had not spread to the more remote parts of the island in 1908, although *R. nativitatis* and *R. macleari* had disappeared completely by that time; (2) moribund individuals of the two native species had been commonly seen in about 1903, after which none were seen at all. Andrews did not suggest reasons for the disappearance of the shrew, which seemed to have occurred in the same brief time span over which the native rats had become extinct.

M.W.F. Tweedie, a collector from the Raffles Museum in Singapore, spent about a month on the island in 1932. Chasen (1933) mentioned his visit and noted that *Mus musculus* and *Rattus concolor* (= *exulans*) were collected on the island in 1932, presumably by Tweedie. However, Chasen, in his 1940 checklist of Malaysian mammals, only reported the rodents *Mus musculus* and *Rattus rattus* on Christmas Island. Even more curious is Gibson-Hill's (1947a) report on investigations he made on the mammals of the island in 1938-1940. He was unable to find either of the two native rats or the shrew there (as one would expect from the information supplied by Andrews,1909), but collected *Mus musculus* and reported that he had also collected a series of 200 rats, which he had sent to Chasen, who had provisionally identified them as *Rattus rattus*, *R. exulans* (as *R. concolor*) and *R. norvegicus* . Gibson-Hill claimed that it was possible to collect *R. rattus* and *R. exulans* anywhere on the island. It is difficult to reconcile this conflicting information, particularly when one reads his paper on birds of Christmas Island and finds that only *R. rattus* and *R. norvegicus* are mentioned (Gibson-Hill, 1947 b). It is perhaps worth mentioning that Chasen was the doyen of mammal taxonomy, at least in the Asian sphere, at that time and Gibson-Hill was another respected figure in the community - the resident medical officer on the island.

The presence of cats on the island from early days is unequivocal, but there is some difference of opinion as to when they became feral. Andrews (1900) recorded that they were not present in 1897, but by 1908 'cats have been introduced and are becoming numerous; in some cases they have taken to the woods....' (Andrews, 1909). Ridley (1906) reported 'There are plenty of cats on the island now but it does not appear that any have taken to the forest....'. Gibson-Hill (1949) echoed this view: 'Ridley saw feral cats there as early as 1904...he also found, as I observed again in 1938-40, that they do not move far from human habitation....' He went on to say that cats did not seem to exist in any great numbers and surmised that the shortage of free water in the dry season may kill off all except those that remained near the settlement. With the benefit of hindsight, and knowing that cats do not need access to free water to survive as long as they have adequate food (Prentiss, et. al 1959), it seems likely that cats have been present in the forested areas of the island since shortly after settlement.

A survey of feral cats was carried out at the end of the dry season in October 1981. In 1981 the mining operation was still in full production with phosphate being extracted from several different areas simultaneously. As a consequence cats had access to human refuse at many different places and nine of the twenty one guts examined contained refuse. They also contained a wide variety of animal remains, but many of these could not be identified fully at the time because of a lack of facilities. The study showed that although cats were widespread on the island, they were concentrated in and around mined areas (Yorkston, 1981).

The surprising twist to this story is that in late 1984 Australian National Parks and Wildlife Service personnel captured a shrew and in early 1985, captured another, both near the western end of the island (see Figure 4 for locations) and both quite by chance. There is no doubt about the identity of the species (*C. attenuata*), for one is now held in the Western Australian Museum, Perth. (D.H. Kitchener, personal communication). These captures, of course, aroused great interest, but attempts to locate further shrews were not successful: (1) pitfall trapping from October 1985 to January 1986 (1500 trap nights) in the vicinity of the 1984 capture site yielded only two *R. rattus* (N. Dunlop, personal communication); (2) pitfall trapping (about 120 trap nights) in primary rainforest near the centre of the island in March to April 1987 yielded no mammals, and in small mammal box traps set nearby only two *R. rattus* were caught (H.Y).

Other fauna

Of the 21 species of birds which now breed on Christmas Island, four are endemic. Some species are quite rare, although no extinctions have occurred, and a number of exotics have become established (Stokes, 1988). Eleven species of reptiles are present on the island, of which four are endemic, and two exotic (Cogger, et al, 1983; Smith, 1988). There are no amphibians or freshwater fish present, although many species of marine fish, including ??? endemics, have been recorded (Reference?). The island is well known ~~for~~ its land crabs, of which there are twelve species?, including six? endemics. Notable among these for its size (>2.5 kg) and numbers is the robber crab, *Birgus latro* and for sheer biomass, the red crab, *Gecarcoidea natalis* , which in primary rainforest occurs at a density of 13,800 crabs ha^{-1}, representing a biomass of nearly one tonne ha^{-1} (Hicks, 1985; Hicks et al, 1984).

The work described in this paper was aimed at gaining basic information on the status and distribution of the mammal fauna It was commissioned by the Australian National Parks and Wildlife Service as part of its research and surveys programmes.

Methodology

Field work

Survey work was carried out on the island in 1984 and 1988. In 1984 four weeks were spent on the island in March and five weeks in August-September; in 1988 eight weeks in June-August. In 1984 the nine weeks were devoted entirely to a study of the two bats present; in 1988 no bat work was done except to collect some insectivorous bats. There was a major difference in accessibility between the two periods: in 1984 virtually all of the plateau area and some of the shore terraces were accessible by four-wheel drive vehicle on a network of tracks which had been bulldozed in 19?? (Hugh) for mining exploration; in 1988 most of these, and some sections of the formed roads as well, were impassable because of a cyclonic wind which had blown over a great number of trees in March of that year.

Microchiropteran bats

Several methods were used to catch microchiropteran bats. (1) Direct observation. Once it had been established that only one species of insectivorous bat was present on the island it was possible to directly record its presence, observe its behaviour and know which species it was. Minimum information recorded was place of sighting. (2) Mist netting. Monofilament mist nets were used in an attempt to catch bats. Mesh size used was 25 mm and net lengths varied from 5 m to 15 m long. Filament thickness was 40 denier. Nets were set up across mining tracks and in other cleared areas, particularly where bats had been seen foraging. Nets were set up at least one hour before dark and monitored for about two hours after. A total of 15 mist net nights were expended in March 1984. (3) Harp traps. Collapsible harp traps (Tidemann and Woodside, 1978) were set up along tracks through the forest. These were erected during the day and checked each morning for two or three consecutive nights at each site. Trapping effort was about 100 trap nights in March 1984 and about the same number in August-September 1984. (4) Hoop nets with a circular metal frame 70 cm in diameter were fitted with handles and loosely covered with braided mist-net mesh. These were used to capture several bats while they were flying at dusk. (5) Shooting. Some animals were collected with a 12 guage shotgun in 1988. Several caves were examined and searched with an ultrasonic detector (QMC Mini) for cavernicolous bats.

A series of pipistrelles was retained for further study. These were weighed and the forearms were measured immediately after death. One testis and the accessory reproductive organs were dissected from males and reproductive tracts were removed entire from females for later studies (Tidemann, in press). Skulls were removed from the bodies and cleaned and then measured with dial calipers under a dissecting microscope. Skull measurements follow the nomenclature of Kitchener et al (1986). The contents of the scats of four animals which were harp-trapped in March and the stomach contents of two animals which were hoop-netted in September, plus the scats of another two animals collected at this time, were examined and partially identified.

Flying-foxes

P. melanotus on Christmas Island is partly diurnal (Tidemann, 1987), so that it was possible to observe and collect foraging animals and look for camp sites during daylight hours. Information on possible camp sites was sought from local people and by direct observation from cliff-top vantage points. This method was also used to make counts of animals leaving camps in order to gain an idea of the size of the population. In situations where there were no vantage points near camps, estimates of numbers were made by counting from the ground below the roost trees. Counts were made at times when we knew there were peak numbers in camps. Other observations of flying-foxes were made while driving or walking through the forest and an inspection of the north coast from Flying-fish Cove to North-west Point was made by boat.

Forty nine *Pteropus* were collected at various locations in March 1984 and 86 in August-September 1984 by shooting with a 12 guage shotgun. Collected animals were examined for ectoparasites, body weights and forearm lengths measured, and their guts were removed for dietary analysis. Skulls were removed from the bodies and cleaned and then measurements were made as for pipistrelles. Other information on reproductive status and age was also taken; these observations are described by Tidemann (in press). Further information on food plants was collected by direct observation of feeding bats and in some instances, food particles were found in the mouths of collected bats. Several instances of leaf eating were recorded by finding ejecta beneath feeding trees.

The guts of ten animals collected in March 1984, ten from the September 1984 collection and seven collected in January 1985 (H.Y.) were examined for the presence of pollen, which was compared with reference material prepared from flowers collected on the island in March and September 1984. Livers and gut contents were also examined for the presence of endoparasites, particularly *Toxocara pteropodis*.

Observations of hunting parties enabled information to be collected about some aspects of predation by humans, and 500 questionnaires (in Malay, Chinese and English) were distributed to families through school children after repeated broadcasts over the local radio station in the three languages. Efforts also were made to discuss bat hunting with several parties of people engaged in this activity.

Small terrestrial mammals

Sampling methods

Two factors made a survey of small terrestrial mammals on Christmas Island difficult: (1) the ubiquitous, omnivorous land crabs, *Birgus latro* and *Gecarcoidea natalis* and (2) the limited vehicular access caused by treefalls from the March 1988 cyclone (See Figure 5).

Small aluminium box traps and breakback traps set on the ground and on the buttress roots of trees were sprung and the bait removed, often within a few hours of being set. Some traps were also badly damaged, for *B. latro* is a large, powerful crab, as well as being an adept climber. 'Crab excluders' designed to protect breakback traps from crab interference, were constructed from sheet aluminium roofing material salvaged from the refuse tip after having been destroyed in the cyclone. The excluders were of two types, one for setting traps on the ground (Figure 3a), and the other for setting traps on small branches in the broken-off tops of trees (Figure 3b). Few problems with crab interference were experienced when these excluders were used. They were subsequently used in all situations, except in regrowth vegetation and in the coastal fringe vegetation (in which crabs are not common during the dry season), where it was found that snap-back traps could be set on the ground or up trees with only a small proportion being sprung by crabs.

When the survey procedures for small mammals were planned it had been assumed that vehicular access along the network of mining tracks would be posible. Accordingly, the extensive use of pitfall traps, dug by mechanical auger had been envisaged. In the event, this was not possible. Twenty five pitfalls were dug with hand tools, in an area of deep soil where a shrew had been captured in

1984. Notwithstanding the depth of the soil it still took an uneconomic length of time to install pitfall traps complete with sheet metal (to withstand crab damage) liners and drift-fences and the use of this method was abandoned.

Preliminary efforts were made to trap owls (*Ninox squamipila*) so that regurgitated pellets could be examined for small mammal remains. Owls are quite common and although they can be called up with tape recorded calls quite easily, they proved more difficult to catch, and the method was not pursued.

The gut contents of cats shot on spotlighting transects were analysed for small mammal remains, as were a few scats collected during the course of other survey work. Only one set of scats was found, probably because they are usually dispersed very rapidly by red crabs.

Sampling strategy

Settlement area

Systematic trapping was not carried out in the settlement area. Instead, residents were offerred a bounty of $1 per animal and the traps to catch them with. This offer was made on several occasions by radio broadcast (in the three languages previously mentioned), and the bounty was increased to $2 for the last three weeks of the study in August 1988.

Non-settled areas

The island away from the settlement was stratified for sampling using the vegetation analysis of Mitchell (1985). Mitchell separated the island vegetation into seven primary vegetation types which are outlined in the introduction. The basic unit of sampling used in this study was a trap line of 24 break back traps set about 15m apart. Twelve of these were set on the ground and these were alternated with twelve which were fixed 1-2 m off the ground on buttress roots or on small branches of fallen trees. In all vegetation types, except regrowth and coastal fringe vegetation, traps were protected from crabs by excluders. Traps were baited with an infusion of aromatic cheese in vegetable oil and they were checked and rebaited daily. They were left at each location for three consecutive nights in all except one instance, in which they were left for two nights only.

Trapping effort was distributed roughly in proportion to the area of each vegetation type on the island. The distribution of trapping effort by vegetation type was as follows (trap line locations are shown in Figure 4): Primary rainforest: line numbers 9,10,24,25,26; Marginal rainforest: line numbers 11,12,13,14,15,17; Cliffs/scree slopes: line numbers 5,6,8,16,29,30; Open forest/vine forest: line numbers 1,2,3,4; Coastal fringe: line numbers 20,27,32; Freshwater seepage: line numbers 7,18; Regrowth: line numbers 19,21,22,23,28,31,33.

Cat Survey

Spotlighting transects and cat collections

A team of three people was involved in assessing cat numbers and collecting animals for examination: a driver, a spotlighter and a shooter. The spotlighter and driver were in voice contact through an intercom system. Surveying was done from a light truck moving at about 20-25 km per hour, depending on terrain and visibility in different vegetation types. The main spotlight used was a 100 watt beam powered by the vehicle's battery. A portable light was used for retrieval of shot animals. Cats were shot with a 5.6 mm centre fire rifle fitted with telescopic sights. Cats seen, but not shot were recorded by location and this information, together with details of collected animals, was recorded onto a hand-held tape recorder and later transcribed. A few cats were opportunistically collected during the course of other survey work.

Four regular transects were set up after some preliminary investigative spotlight runs. Because there was considerable overlap between runs due to available roading on the island the runs have been broken down into twenty three component segments (Figure 5) for analysis. Various combinations of these were run on fifteen different nights. Information on sampling effort in different vegetation types is summarised in Table 2. Only four vegetation types are shown: primary rainforest; marginal rainforest; open forest-vine forest and regrowth. Although the transects also passed through cliff/scree slope vegetation this has not been included in the summary for visibility in this vegetation was virtually nil. In other vegetation types transect visibility widths ranged from 15 to 250 m (80 ± 78; n=10). No examination was made of vegetation on freshwater seepages or the coastal fringe, for no readily trafficable roads pass through these vegetation types and wandering around such areas at night is quite hazardous, due to the difficult terrain.

Table 2: Spotlighting transects for cat sampling broken down into the component segments shown in Figure 5. Each segment is further broken down into the distance traversed in each vegetation type (m) and the number of times each segment was traversed. Total distances travelled through each vegegation type (km) are summarised at the foot of the table.

Segment number	Primary rainforest	Marginal rainforest	Open forest vine forest	Regrowth vegetation	Number of replicates
1	1200	450	-	1800	6
2	1450	1000	-	1350	6
3	-	-	-	900	12
4	-	3300	-	900	13
5	-	-	-	700	14
6	1700	-	-	1200	3
7	-	200	-	950	4
8	-	1300	4900	5600	3
9	-	-	-	1650	8
10	1800	-	-	2250	12
11	1400	800	-	-	3
12	1800	1950	-	-	2
13	1700	300	-	-	5
14	-	-	-	400	4
15	-	-	-	650	1
16	1450	-	-	250	5
16a	850	-	-	250	1
17	900	300	-	1900	7
18	1500	600	-	2400	8
19	800	-	-	2000	6

20	1100	-	-	6000	11
21	-	-	-	2700	5
22	1200	-	-	750	1
TOTALS:	105 km	71 km	15 km	247 km	438 km (overall)

Macroscopic gut examinations

Cats shot during spotlighting runs and a few from other sources were measured and dissected within a few hours of death. Sex, body weight, fur colour, body fat and reproductive condition were recorded and the entire digestive tract was removed from each animal and preserved in 10% formalin. Skulls were also retained and the rest of the carcases were discarded. In the laboratory the preserved cat guts were dissected and examined. Stomach contents and faecal material (including the single set of scats collected) were examined separately after soaking for 24 hours in a solution of detergent in water followed by washing in a 2.5 mm mesh sieve.

The washed material was examined and sorted macroscopically by eye and in some cases with a dissecting microscope. Stomach contents in many cases were readily identifiable macroscopically. Cats do not chew their food much before swallowing, except in the case of large prey. Mice, small rats and most lizards were swallowed whole, as were most invertebrates, but large rats, pigeons and other large birds had been chewed into chunks before they were swallowed. Most invertebrates and lizards were identifiable in this way as were some mammals and birds. Where there was doubt with mammals or birds fur or feather samples were examined microscopically.
Faecal pellets/scats, on the other hand, were well macerated and in most cases required microscopic examination for the contents to be identified. Representative examples of gut parasites were retained and identified.

Microscopic examinations

Fur samples from cat guts and scats were identified using the methods of Brunner and Coman (1974). Reference material was obtained from various sources: fur of *R. macleari* and *R. nativitatis* was supplied by the British Museum (Natural History) from specimens collected on Christmas Island by Charles Andrews; fur of *C. attenuata* was provided by the Western Australian Museum from the animal collected by ANPWS staff in 1985. *R. exulans* fur was supplied by the W.A. Museum from animals collected in south-east Asia and fur samples of the other species (*R.rattus, R. norvegicus, Mus* and *Felis*) came from B. Triggs' reference collection of specimens collected in Victoria and New South Wales.

Feather samples were identified using methods developed by Alison Rowell (Bird Hazard Investigation Unit, Civil Aviation Authority) following procedures described by Brom (1980). Reference material for this work was provided by CSIRO Division of Wildlife and Ecology, Gungahlin, ACT, from specimens collected on Christmas Island. Reptiles were identified directly from descriptions provided by Cogger et al (1983). Invertebrates were identified to species in only a few cases, for example red crabs, but the majority were taken only to order level, for example, cricket, grasshopper, moth.

Counts of the number of individuals of particular prey items were made, where this was possible, or estimated where it was not. Mean body weights of prey items were collected from various sources (Table 7) and these were used to calculate the total weight of prey items in cat diet. This method was chosen as being superior to the practice of weighing the contents of individual guts because it circumvented the problem of differing degrees of digestion, as well as being quicker.

Gut contents from three animals collected in August 1984 (this study), two collected in May 1987 and two in November 1987 (by D. Phillips), and 21 of the cats which had been collected in October 1981 (Yorkston,1981) were also included in the analyses. A total of 94 guts and one set of scats was analysed.

RESULTS

Christmas Island Pipistrelle *Pipistrellus murrayi*

Captures

No bats were caught in mist nets. Harp traps caught them, but in low numbers. From the 100 trap nights in March 1984 nine animals were trapped, and from the 100 trap nights in September 1984 19 animals were caught. Shooting was also effective and twenty one pipistrelles were collected in this manner in June-August 1988. Two bats were caught with hoop nets, but in order to catch them by this method one had to strike so quickly that the momentum of the impact, little as it was (body mass 3 g), destroyed the animal's life and shooting seemed a much more efficient way of doing this. Locations at which bats were collected or observed are shown in Figure 6. No bats or ultrasonic vocalisations were recorded in caves.

Morphometrics

Body and skull measurements of pipistrelles are presented in Table 3. Comparison by ANOVA showed there to be no significant sexual dimorphism in any of these. Additionally, there is remarkable uniformity between individuals, as evidenced by the very low variances.

Table 3. Comparison of selected body and skull measurements of male and female *Pipistrellus murrayi* (means ± S.D.). Measurements are in mm, except body weight, which is in g; sample size is 11 in each case.

Measurement	Males	Females
Body weight	3.1 ± 0.2	3.2 ± 0.1
Forearm	31.0 ± 0.6	31.2 ± 0.7
Greatest skull length	11.9 ± 0.2	11.8 ± 0.2
Braincase width	6.2 ± 0.3	6.2 ± 0.1
Palatal length	4.9 ± 0.2	4.9 ± 0.2
C^1 - M^3	4.1 ± 0.1	4.1 ± 0.1
Post palatal width	1.6 ± 0.1	1.6 ± 0.1
Dentary length	8.4 ± 0.2	8.5 ± 0.2

Foraging behaviour and diet

Bats were observed flying from 1.5 h before sunset until dawn, although the peak of activity was in the 45 min immediately after sunset and there was an almost complete cessation of activity for about two hours afterwards. Renewed activity was apparent from about 2000 h until midnight. On several occasions during daylight hours bats were seen foraging in company with feeding swiftlets, *Collocalia esculenta*. Foraging bats were seen at all heights from just above the ground up to 20 m above forest canopy height (about 35 m). Along tracks in closed forest bats flew from 0.1 m to about 3 m above the ground, skilfully avoiding overhanging vegetation and the ubiquitous spiders' webs. Many instances of aerial prey capture were observed, but none from the ground surface or from vegetation.

Insects identified from faecal pellets and stomach contents were: moths, thrips, chrysomelid, scarabid and other beetles, micro-wasps and flies. There was a general predominance of small beetles and moths both in March and September 1984.

Christmas Island Flying-fox *Pteropus melanotus*

Distribution of *Pteropus* on Christmas Island

Five large aggregations of *Pteropus* were found and examined in 1984, and another two were subsequently located by H.Y. The locations of these camps are shown in Figure 1. The camp at Daniel Roux Cave was estimated to contain 150 bats in September 1984. It was deserted in March 1984 and was again unoccupied in March 1985 (A. Stokes, personal communication.). It had originally been observed in August 1970, when "two or three trees were covered in bats" (G. Collins, personal communication). In September 1984 the roosting animals were confined to three *Pisonia* trees. The Hosnies' Springs camp is known by local residents to have been used for a long time (Wah Chee, personal communication). This camp was occupied in March 1984, but counts were not made at this time. Emergence counts made on 7 September and 17 September 1984 yielded numbers of 1543 and 2121 respectively. This roost was located in the canopies of several *Ficus* sp.

Flying foxes were observed in the Middle Point camp in June 1984 (A. Stokes, personal communication). In September 1984 it was estimated to contain 300 bats. In most of the trees the bats shared roosting space with Red-footed boobies, *Sula sula rubripes*, in five emergent *Pisonia*. Emergence counts from the camp at Ethel Beach in September 1984 indicated that about 130 bats were in occupancy. The camp was located in five *Barringtonia racemsosa*.trees. Three hundred animals were estimated to occupy the Stronach Knoll camp in March 1984, but in September of that year in excess of 1000 bats were probably roosting in this location. Roosting animals were dispersed through a number of trees, mostly *Ficus* and *B. racemosa.*

Two other roosting aggregations have since been located by H.Y., one at McMicken Point and the other at Dolly Beach. Reports of a camp at Dolly Beach were received from locals in 1984, but it was not found at that time. It was estimated to contain xxx animals in ??? (Hugh?), roosting in ???? The McMicken Point camp was found by chance in November 1988, when it was estimated to contain about 100 flying-foxes roosting in three ?????? trees.

Dispersed Individuals

During the inspection of the north coast of the island by boat it was noticed, in addition to the camp located at Daniel Roux Cave, that many bats were roosting singly or in small, loose groups of three or four, in stunted *Pisonia* and *Terminalia*, all the way along the coast to West White Beach, but not beyond. This is where the vegetation changes from cliff/scree slope type to OF/VF. High densities of such groups were observed particularly around Rhoda and Margaret Beaches. Other similar dispositions of roosting bats were observed elsewhere on the shore terraces of the island. Such a group was observed 2 km west of the Middle Point camp on 4 September 1984, when it contained five animals. On the following day only three bats were present in the same position.

How many *Pteropus* on the island??

Table 4 Analysis of sexual dimorphism by ANOVA of skeletal and body dimensions of adult *P. melanotus*. Dimensions in mm. (means ± SD)

Dimension	Males n=19	Females n=46	Significance
Body weight	???	???	???
Forearm length	128.9 ± 2.7	128.0 ± 2.8	n.s.
Basal length	56.3 ± 0.8	55.4 ± 0.6	****
Palate length	27.4 ± 0.6	27.1 ± 0.5	*
Zygomatic width	30.1 ± 0.6	28.7 ± 0.6	****
Width C^1-C^1	11.7 ± 0.3	11.3 ± 0.2	****
Width M^2-M^2	15.8 ± 0.4	15.8 ± 0.3	n.s.
Rostral width	10.1 ± 0.2	9.7 ± 0.2	****
Supraorbital width	21.6 ± 0.8	20.3 ± 0.7	****

n.s. not significant; * < .05; **** < .0001

Although the sexes are significantly dimorphic in a few dimensions, they are not much different. Note also the high degree of uniformity in the measurements cf *Pipistrellus* and no doubt indicative of a low degree of genetic variance.

Foraging Behaviour

An extensive proportion of the foraging activity of *P. melanotus* occurs during daylight hours and at least a few bats can be seen flying above the canopy at almost any time of day. There is a pronounced peak of activity from 1430 h to 1830 h and a secondary, lesser peak shortly after sunrise. Many bats observed during the night were asleep or, at least, inactive (Tidemann,1987).

Feeding individuals appeared to be spaced randomly with respect to each other, with the exception of lactating females and their young. However, it was rare to find more than five or six bats in the one tree, suggesting some degree of spacing. Strict counts of feeding bats per tree were not made and it is not possible to say if there was evidence of flock foraging or not. Many bats were seen feeding on their own and, during inactive periods, roosting separately in feeding trees.

Attempts to obtain information on commuting distances between roosts and feeding areas by radio tracking were thwarted by several factors. However, many bats were seen to fly great distances after gaining height by circling above their roosts. Extremely rapid movement was facilitated, once bats had gained height, by strong, steady winds. Bats used these winds to advantage, in many cases soaring, with little wing movement, other than adjustments to the aerofoil, for very long distances. In some cases they flew out of binocular view, at least 5 km away. Return to the camps in the morning was usually accomplished at or near canopy height, at least by those individuals which had to return against the prevailing wind.

Diet

In March 1984 the stomachs of all animals shot (49) contained granules and some seeds from the fruit of *Muntingia calabura* and virtually all bats appeared to be using this as a primary food source. *M. calabura* grows initially as a shrub and later as a small straggling tree, rarely exceeding 6 m in height. Fruit is borne separately along the foliated length of branches, even when the plant is quite small. The seeds are small enough to be swallowed by flying-foxes. Foraging bats were observed to feed on these fruits at all heights in the plant from the top of the canopy to near ground level. Such behaviour makes them particularly prone to predation by *Felis* and people. Many *Pteropus* were seen feeding on other fruiting species in March, particularly *Terminalia*, *Planchonella* and *Mangifera* and on the flowers of *Cocos* and *Barringtonia*.

During late August and the first half of September 1984 bats were feeding mainly on *Syzigium operculatum*, which was fruiting profusely in the rainforest at that time. By the end of September nearly all the *Syzigium* fruit had been exhausted and it was only at the end of this period of field work that bats were again observed in the *Muntingia* in any numbers. The changeover was very noticeable and was complete within two to three days. Similar abrupt changes in feeding behaviour have been observed since (Hugh, have you got any more details??). Other information on the diet of *P.melanotus* is summarised in Table 5 Many other unidentifiable pollen taxa were also isolated (Figure 7).

Table 5 Food plants of *Pteropus melanotus* on Christmas Island

Family	Species	Flowers	Fruit	Leaves
Anacardiaceae	*Mangifera odorata*		+	
Arecaceae	*Arenga listeri*	+		
	Cocos nucifera	+		
Combretaceae	*Terminalia catappa*	+	+	
Caricaceae	*Carica papaya*		+	
Euphorbiaceae	*Macaranga tanarius*	+		
Flacourtiaceae	*Muntingia calabura*		+	
Lecythidaceae	*Barringtonia racemosa*	+		
Meliaceae	*Dysoxylum gaudichaudianum*	+		
	Melia azedarach	+		
Moraceae	*Ficus* spp.		+	+
Myrtaceae	*Psidium guajava*		+	
	Syzigium operculatum		+	
Rubiaceae	*Morinda citrifolia*	+		
Sapindaceae	*Tristiropsis acutangula*	+	+	
Sapotaceae	*Planchonella nitida*	+	+	
Solanaceae	*Physalis* sp.	+		

Ulmaceae	*Celtis timorensis*		+
Urticaceae	*Dendrocnide* sp.	+	
	Pipturus argenteus	+	

Barringtonia racemosa Hugh, what is this species that grows along the coastline called now?? It does not appear in the most recent list under Lecythidaceae.

Parasites

P. melanotus on Christmas Island is remarkably parasite free. No internal parasites were found in flying foxes from Christmas Island, although particular attention was paid to the possible presence of *Toxocara pteropodis*, which is a common endoparasite of Australian and some island populations of *Pteropus* (Prociv, 1987). However, despite the fact that the alimentary tracts and livers of well over one hundred individuals were examined, no *Toxocara* were seen. Two species of ectoparasite were collected from flying foxes, but only one individual of each was found: a hippoboscid fly, *Olfersia aenescens*, and a spinturnicid mite, *Meristaspis calcarata*. *O. aenescens* is a parasite of sea-birds (*Fregata* and *Sula*), but it has a tendency to wander onto strange hosts (D. Colless, personal communication). *Meristaspis* mites are common parasites of flying-foxes elsewhere, although they are usually present in larger numbers (Prociv, 1987).

Predators

Predators of flying-foxes on Christmas Island are all recent arrivals - humans, feral cats and rat snakes. The colubrid rat snake, *Lycodon aulicus*, a widespread Asian species, was accidentally introduced to the island in mid-1987 (Smith, 1988). It appears to have become established, because since 1987 about 30 different individuals have been seen (D. Phillips, personal communication). Such a species could become a serious predator of *Pteropus* on Christmas Island, as *Boiga irregularis*, an import from Australia, has on flying-foxes (Wiles, 1987) and birds (Smith, 1988) on Guam. *L. aulicus* is arboreal and usually feeds on reptiles and small mammals.(Smith, 1988).

One instance of a goshawk, *Accipiter fasciatus*, eating a flying fox has been observed in several years of observation, but this species usually preys on birds (B. Reville, personal communication). Many instances of young frigate-birds (*Fregata* spp.) jostling flying foxes were observed during this study (also reported by Cheke and Dahl, 1981), and on one occasion a kestrel, *Falco cenchroides* was seen to pursue and occasionally strike a flying fox. Attacks such as these are unlikely to cause mortality, although they could, on occasion, cause minor injuries.

The efficient method used by humans for hunting flying-foxes on Christmas Island was described by Tidemann (1987). It is difficult to gauge the extent of hunting of flying foxes on the island. Firearms are prohibited, and for this reason bats are not harvested from camps because they are out of reach in tall trees. Hugh is it still permitted?? Bats for sale/ timing of hunting coincides with birth season cf Mickleburgh et al, (in press).

Small terrestrial mammals

Settlement area

A total of 33 small mammals from the settlement area, all of which were *R. rattus*, were proffered for examination by various individuals. Several people also reported the presence of *Mus* in houses, and although no specimens were sighted, there seems no reason to doubt these identifications.

Non-settled areas

From a total of 2036 trap nights 59 small mammals were caught. Of these 53 were *Rattus rattus* and six were *Mus musculus*. *Rattus rattus* was caught in all vegetation types except marginal rainforest, in which nothing except one thrush was trapped. However, the numbers of rats caught per trap night varied considerably between the different vegetation types. Primary rainforest and vegetation on cliffs/scree slopes , freshwater seepages and open forest-vine forest all showed similar rates of captures : 8.6, 8.1, 7.6 and 7.1 rats per 1000 trap nights respectively. Regrowth vegetation returned a ten-fold increase over these rates with an average of 74 small mammals (rats and mice) per trap night. Capture rates in coastal fringe vegetation (*Scaevola*) were higher again, at an average of 120 rats per 1000 trap nights. Information from cat gut contents confirmed the trapping results and added to the picture of rat distribution on the island (Figure 8).

The only locations at which *Mus* was trapped were in trap lines 28 and 31, both in regrowth vegetation. However, this species was also recorded from sixteen of the cats shot in 1988, and these came from widely distributed locations on the island (Figure 9). Of the sixteen all but one were shot in regrowth vegetation and the other from less than 500 m away from the nearest patch of it. Two conclusions seem reasonable: firstly that cats are more effective at catching small mammals than traps are, and secondly that mice are fairly widely distributed on the island, but are almost certainly restricted to regrowth. Although one cannot be certain that a cat which has a mouse in its gut has caught it at the place at which the cat is shot, it seems reasonable to assume that it has probably not caught it far away.

Several non-target species of vertebrates were also caught in the traps: six thrushes (*Turdus*), one emerald pigeon (*Chalcophaps*) and one gecko (*Cyrtodactylus*).

Feral cats

Cat numbers in different vegetation types

It is possible to establish absolute densities of animals by line transect procedures (Morgan, 1986). To do this it is necessary to make measurements of distance from the transect line to the observed animals with a rangefinder or some other method. This takes time, and it was considered more important in the present study to shoot observed cats quickly before they disappeared. Consequently, only statements about the relative numbers of cats observed in different vegetation types can be made.

A total of 438 km was travelled during the cat spotlighting transects, and a total of 37.8 h were spent on this activity (113 man-hours). During this time 57 animals were shot and retrieved and an additional 74 sightings were made (Figure 10). A concentration of animals can be seen at the refuse dump. It is worth noting here that of the 74 sightings some may have been seen more than once and almost certainly some would have been shot on subsequent occasions. If total kills and sightings are considered together 131 sightings and kills were made over 438 km, i.e. an average rate of 30 cats per 100 km (Table 6).

Table 6: Cats seen, but not killed, and cats killed in different vegetation types.

Vegetation type	Cats Seen	Cats Killed	Total Cats	Distance (km)	Cats /100 km
Primary rainforest	8	5	13	105	12
Marginal rainforest	4	3	7	71	9
Open forest/vine forest	2	2	4	147	3
Regrowth	60	47	107	247	43

As was found with small mammal capture rates, the rate at which cats were seen varied between vegetation types. The highest rate at which cats were observed was in regrowth vegetation - 43 cats per 100 km of transect, which far outweighed the much lower numbers observed in other vegetation types.

Cat diet

The results of the analysis of cat diet are presented in Table 7 Results have been separated into animals which contained human refuse in their guts (commensal) and those which did not (feral). Cats with completely empty guts have been excluded. Of the 21 cats collected in 1981, one gut was empty and nine contained human refuse; of the remaining animals two guts were completely empty and another nine contained human refuse. Five of the eighteen guts containing human refuse also contained small quantities of plant material, mostly grasses, compared to 31 out of the 74 guts which did not contain human refuse.

Table 7: The relative importance of different prey types in the diet of 92 cats on Christmas Island. Animals have been segregated according to whether their guts contained human refuse (commensal) or did not (feral).The sources of the mean body weight information for the different prey types is given in a footnote to the table.

The relative importance of different prey items is compared by percent occurrence in the 92 different guts with their relative importance as a contribution to the total estimated weight of the totalled contents, ie 13.8 kg for feral animals and 1.1 kg for commensals. These two methods of analysis give quite different results. For example, grasshoppers were present in 42 of the 74 feral guts examined, which represents 57% of cats. Many cats ate more than one grasshopper and a total of 240 individuals was counted. However, as a contribution by weight this represents lonly 2.5% of the total 13.8 kg. By contrast, only eight cats had eaten Imperial Pigeons, *Ducula whartoni,* but this made a contribution of 30% of the total food intake of feral animals.

For discussions concerning the importance of a particular prey item to cats it is the percentage by weight which is important. Thus, flying-foxes, *Pteropus,* rats, *R. rattus* , and Imperial pigeons, *Ducula,* together constituted 83.5% of the total food intake, by weight, of feral cats. Invertebrates, excluding red crabs, *Gecarcoidea,* are eaten by many feral cats, but do not make much of a contribution by weight - less than 3%. As far as the importance of cats to the population numbers of a particular prey species goes, it is the numbers of individuals eaten. Geckoes, *Cyrtodactylus* sp nov., were present in 25.5% of feral cat guts, but only made a weight contribution of 3.5%. But, many of the 19 cats had eaten more than one gecko, with a total of 57 individuals being identified. It is this number which is significant in questions of management of the gecko population.

A major difference between commensal and feral animals was observed in the quantity of red crab eaten by these two groups. Red crab was present in 50% of commensal cat guts compared with only 12% of the feral group. Indications are that crab is not a preferred food item and is probably eaten only as scavenged food from road kills. The percentage weights may underestimate the importance of red crab to the cat population because each cat which contained crab fragments was scored as having eaten only one individual. It may be that some cats had consumed more than one crab, but it was not possible to ascertain this, because in all cases the exoskeleton was greatly fragmented.

Reproduction and body condition

Information on reproductive status is available for 68 animals collected in 1988. Of these, 38 were male and 30 female. If only animals which had obtained reproductive maturity are considered (females lactating, pregnant or parous; males with fully enlarged testes) the ratio is quite different: 30 males and 13 females. Body weights (mean $\pm$ SD; range) of these were 3.8 $\pm$ 0.6; 3 - 5.25 kg for males and 2.8 $\pm$ 0.4; 2.25 - 4 kg for females.

Sexual maturity in females on Christmas Island appears to be attained at a body weight of about 2.5 kg and in males at about 3 kg, although these figures are not absolute. One female of 2.25 kg was found to contain 3 foetuses and several of 2.5 kg were nulliparous, although they may have been in early pregnancy, which would probably not have been detected by the macroscopic examinations made. Yorkston (1981) reported one female of 2.2kg lactating and another of the same weight in early pregnancy in October. Of the 13 mature females which were collected in 1988, one was lactating and six were pregnant. The number of foetuses was recorded from five of these. Three animals had three foetuses in utero and one each had two and four, respectively. Several animals of less than 1 kg, and still clearly dependent, were obtained, suggesting that breeding may be more or less continuous throughout the year on Christmas Island. There was not, at least, a cessation of reproduction during the dry season of 1988 and in October 1981 Yorkston collected one animal of less than 1kg, and recorded one pregnant female and one lactating.

It is not possible to ascribe actual ages to the body weights of 2.5kg and 3kg for females and males , but these are likely to be about 10-12 months and 12-14 months respectively. Studies of age in feral cats are few and these have been conducted in environments unlike Christmas Island. Wide variation is known to occur between different breeds of cats in variables such as age at sexual maturity, gestation period and litter size, among others and environmental factors can also have an effect (Jones and Coman, 1982 a).

Body condition of most animals, with the obvious exception of juveniles and small subadults, was good, with medium to heavy deposits of subcutaneous and visceral fat present. Young animals were generally thin and in poor condition. It seems likely that survival is most problematical for animals at this stage of life as was found by Pascal (1980).

Endoparasites

As with the general body condition gauged by the fat index, most cats were also in good health so far as internal parasites were concerned. Endoparasites were present in most cats, but the numbers were not great. Most cats had only a few worms present. Three species were identified: a tapeworm, *Taenia taeniaeformis*; a nematode, *Toxocara cati*; and an acanthocephalan, *Oncicola sp.* The intermediate host for the tape worm is usually a mouse, or possibly rats, whereas for the acanthocephalan it is more likely to be a bird. The nematode does not use an intermediate host (M.J. Howell, personal communication).

Coat colour

Of the 82 cats from Yorkston's 1981 sample and this study for which coat colour was recorded, coat colours were present in the following proportions: tabby (29), ginger (23), grey (11), ginger/white (5), black/white (5), black (3), black/orange/white (3), tortoiseshell (2), white (1).

Discussion

Christmas Island Flying-fox *Pteropus melanotus*

Pteropodids are well known for their habit of communal roosting, sometimes in extremely large aggregations containing hundreds of thousands of individuals. Some of the best documented examples of this are in the Australian species, *P. poliocephalus* and *P. scapulatus* (Nelson, 1965). However, species which form camps of this size may be unusual and the more common situation appears to be for camps of a few hundred bats. This could simply be because of population declines, who knows?? *P. niger* on Mauritius forms some camps of a few hundred bats, while many appear to be spread through the forest in small groups of 1-15 animals (Cheke and Dahl, 1981). *P. t onganus* roosts communally in groups of up to a few thousand (Sanborn and Nicholson, 1950; Wodzicki and Felten, 1975). *P. giganteus* colonies may contain a thousand bats (Neuweiler, 1969).

Roost site fidelity is typically high in colonially roosting species. Once formed, a pteropodid camp is likely to be used for a long time, despite interference from man or other agents such as cyclones. McCann (1934) recorded that *P. giganteus* had been using traditional roost sites for at least 60 years and Kingdon (1974) observed that *Eidolon helvum* had been occupying some of the same roost sites in Kampala since pre- European days. Even when one site was cleared and later replanted bats eventually returned to the same area. *P. seychellensis* uses traditional sites, some of which have been in use for more than 30 years (Cheke and Dahl, 1981) and the few remaining individuals of *P. rodricensis* roost in a traditional camp site, which is now nearly all covered in exotic vegetation (Carroll, 1984). In Australia we are familiar with several *Pteropus* camps which have been used by bats for more than 60 years, despite continued and frequent 'bat shoots' and other disturbances. *Hypsignathus monstrosus* does not form camps, but males display sexually to females in leks, the locations of which are traditional. Bradbury (1977) reported that specific leks had been used as far back as any of the local inhabitants could remember. Clearly, traditional assembly areas are central to the biology of many pteropodids and their location may remain invariant for many generations.

On Christmas Island the Hosnie's Springs camp and the Dolly Beach camp are known by local people to have been in use for a long time. There was a camp near the settlement on Christmas Island, possibly the one near Daniel Roux cave, that was occupied in 1897 (Andrews, 1900). This camp was in use in 1970 and the fact that everything in that area in 1984 was periodically covered with phosphate dust from the nearby driers suggests that the bats are relucant to abandon the site in the face of disturbance. The duration of use of the other camps on the island is unknown, but they are likely to be traditional and any serious disruption of them may have a profound effect on the species' ecology.

It is unclear on what basis camp sites are chosen, but in a number of species inhabiting islands, with the notable exception of *P. livingstonii* (Carroll and Thorpe, 1991) camps are formed on or near the coastline. *P. rufus* roosts near the coast of Madagascar (Andersen, 1912) and on Niue Island *P. tonganus* roosts within 2 km of the coast (Wodzicki and Felten, 1975). In the Mariana Islands *P. mariannus* congregates predominantly around the coast (Wiles, ??) and on Rodrigues the only surviving colony of *P. rodricensis* is located about 1 km from the shore (Carroll, 1984).

The benefit to be gained by roosting close to the shore may be the same which accrues from roosting in canopy emergents, namely easy take-off and landing and ready access to the wind currents which flow up from the coast in most places. Andersen (1912) reported that *P. seychellensis* often soared to great heights from which it was able to "fall down" on feeding areas, and *P. s. comorensis* utilizes local updraughts to gain height on the way to feeding grounds (Cheke and Dahl, 1981). *P. mariannus* commonly roosts on sheer limestone cliffs, which afford a similar advantage (Wheeler, 1979) and Cox (1983) described soaring behaviour using updraughts in *P. samoensis*. On Christmas Island dispersal to feeding areas by *P. melanotus* was likewise greatly facilitated by wind currents. Many bats about to leave a roost were seen to wait for a particularly strong wind gust before launching themselves from roost trees. The advantages of a maternity camp placed in a windy spot to young bats learning to fly may also account in part for the location of these. Unfortunately the tendency for human land use patterns to also be more intense near the coast has often brought flying foxes into conflict with them sooner than if they roosted further inland.

The tendency of flying foxes to roost close to the shore has some disadvantages in cyclone- prone areas. Various authors have noted that the decline of several species is attributable in part to the devastating effects of cyclones (for example, Cheke and Dahl, 1981) and others have observed that *Pteropus* in cyclone areas use two sets of roosts, one when the trade winds are blowing and the other during the monsoon season (Racey and Nicholl, 1984; Wheeler, 1979).

Perhaps half of the *P. melanotus* population did not appear to use camps at all, at least at the time of this study, and this characteristic has also been reported in other species. Cheke and Dahl (1981) observed that *P. niger* formed some large camps, but the majority of animals seemed to be spread through the forest in small groups of one to fifteen. *P. ornatus* also forms camps, but isolated individuals can be found scattered through the forest (Sanborn and Nicholson 1950) and Wheeler (1979) thought that *P. mariannus* may have existed, some in camps and others scattered. Cox (1983) believed that *P. samoensis* did not form camps at all, but was dispersed as mated pairs. Thus, the habit of forming camps is common to most members of the genus, but not all individuals in a population are necessarily involved in camp formation. This behaviour makes it difficult to reliably census such populations.

Prociv (1987) thought that the absence of *T. pteropodis* in *P. melanotus* on Christmas Island indicated that bats had invaded the island gradually. South-east trades and norh-west monsoons both in direction of Nias Enggano Nicobars Andamans and then back would keep continual mixing of genetic material. Interesting to test this hypothesis. Probably more intermixing than from Java. What are wind roses for CI?? Would this also work for pipistrelles. Probably not because they are such weak fliers wing loading?? would have to keep flapping unlike *Pteropus* and *Chalinolobus* (Tidemann, 1986) Therefore genetic isolation and endemic. Would also favour rafting?? currents may be different. cf *Crocidura* on Java and Christmas. How far could *Pteropus* soar what is wind speed and flight speeds etc, distance between islands in the chain. Populations on other islands etc etc (Abdulali, write to S.A. Hussein)

Little sexual dimorphism and little intrapopulation variation cf *Pipistrellus*.

How many bats per ha of cleared/uncleared land?value of *Muntingia* to population benefit in revegetating cleared land and responsible for pollination (maybe) of how many species of plants in forest plus fruits

Christmas Island Pipistrelle *Pipistrellus murrayi*

Endemic species cf Koopman etc etc. Unlike many/most vespertilionids *P. murrayi* exhibits no sexual dimorphism, at least in the dimensions examined in this study. Kitchener et al (1986) found little sexual dimorphism in Australian species of this genus. The species also exhibits a remarkable degree of uniformity among individuals, presumably indicative of a restricted gene pool.

P. murrayi seems to be widespread on the island and to occur in a wide range of vegetation types. It can be seen foraging over regrowth areas, although trees large enough to contain cavities do not occur there. The evidence is not conclusive, but it is probably a tree-hole species. None were seen or heard with an ultrasonic detector in several caves which were examined and the species was not distributed patchily through the forest as one would expect of a cavernicolous species. Efforts to radio-track animals back to their roosts proved futile as they were quite unable to carry the 1g transmitters, the lightest available at that time. Tidemann and Flavel (1987) successfully tracked one species (*Vespadelus vulturnus*) with a similar body weight, but the wing loading of *P. murrayi* is quite different.

In the absence of competition from other insectivorous species on Christmas Island *P. murrayi* is able to exploit insects from all strata in the forest. It is an extremely manoeverable flier and its skill in dodging spider webs and hoop nets also mean that it cannot be caught in mist-nets. *Phoniscus papuensis* (Woodside et al) *P. murrayi* has slightly relaxed the usually nocturnal habits of bats, but to nowhere near the same extent as *P. melanotus*. Tidemann (1987) hypothesised that the diurnality observed in *P. melanotus* was due to an absence of diurnal avian predators and it would appear that the same reason may allow pipistrelles to fly in daylight with impunity from predation. Moore (1975) attributed similar behaviour in *Nyctalus* spp. to an absence of avian competition or predation. Even though pipistrelles were observed foraging with swiftlets, *Collocalia*, on several occasions, no agonistic interactions of the type described by Moore between bats and hirundines were observed. What are predators of *Pipistrellus*? Owls certainly hawk large insects from around lights and McCann (1933) reported *Ninox scutulata*, a closely related species, catching pipistrelles by this method in India. However, analyses of gut contents of *N. squamipila* on Christmas Island have not found any mammals at all (see discussion on *Crocidura*).

The reproductive cycle of *P. murrayi* is typically vespertilionid and it seems to be another tropical sperm-storing species (Tidemann, in press). If so, the function seems likely to be one of synchronising births so as to coincide with the onset of the rainy season and consequent peak insect numbers.

Christmas Island Shrew *Crocidura attenuata*

The status of the shrew remains equivocal, but one thing seems fairly certain: it is now present, if at all, in exceedingly low numbers and warrants listing as locally endangered. Lister (1888) and Andrews (1900) described its shrill cry, like that of a bat, being frequently heard, but thousands of hours of night-time work by the authors has failed to disclose any such calls (the main energy component of *Pipistrellus* is at about 60 KHz, so it is completely ultrasonic). Neither was any evidence found of its presence on the island from trapping or from cat gut analysis and if it were not for the two animals caught in 1984 and 1985, there would probably be little further discussion about it. One cannot be sure that trapping or cat gut analysis, for reasons discussed below, would have produced evidence of shrews even if the species was still extant on the island.

The genus *Crocidura* is a very large and diverse one with the number of described species approaching 200 (Honacki et al, 1982). These species exhibit wide variation in size, habitat preferences, geographic range and behaviour (see, for example, Meester, 1963; Harrison, 1964; Roberts, 1977; Smithers, 1983). Thus one cannot be at all sure that statements which apply to one species of *Crocidura* will also apply to another. There appears to be no ecological information available on *C. attenuata* except for the very scant accounts provided by Wharton (1887), Lister (1888), Andrews (1900) and some unpublished observations by H. Yorkston on the animals captured in 1984 and 1985.

C. attenuata was common on Christmas Island at the time of settlement and was apparently nocturnal. Some species of *Crocidura* are completely nocturnal (Vogel et al,1981), whereas others are partly diurnal (Roberts, 1977). Wharton (1887) reported that three animals were caught at night in a pitfall trap and Andrews (1900) reported that the animals' calls were heard at night, so one can assume that the species was at least partly nocturnal and this is substantiated by the observations of captive animals (H. Yorkston, unpublished observations). *C. attenuata* was also said to be common in all vegetation types, but care must be taken in interpreting these statements. It must be borne in mind that early workers on the island would have had great difficulty in moving about in the absence of tracks and it is likely that they were able to sample only in certain areas. The individual captured in 1984 was in primary rainforest and the 1985 capture was on the interface between marginal rainforest and cliff/scree slope vegetation.

It is not certain if *C. attenuata* would enter a trap of the type used in the present study. It could be caught in pitfall traps and other traps as well (Lister, 1888; Andrews, 1900), but is not possible now to determine exactly what these other traps were. It is probably safe to assume that they would have been either some sort of box trap, or breakback traps. *Crocidura* spp. have been caught in Longworth traps (Medway, 1966) and in Elliott traps (Happold and Happold, 1987). Both of these trap types are enclosed metal boxes, not unlike the traps used in the present study. Although some *Crocidura* spp. can be caught in box traps, pitfalls are a far more effective way of catching them in Europe (P.D. Jenkins, in litt.).and Harrison (1964) reported that these shrews were seldom taken in box traps although they could be caught fairly readily in snapback traps using cheese as bait.

The original intention had been to use pitfall traps as a major survey technique for small mammals, but this plan was abandoned for reasons discussed in the methods section of this paper. Pitfall trapping still seems the most likely way to establish the presence of *Crocidura* on Christmas Island, but it would be essential that it be done with a vehicle mounted auger. Pitfalls need to be deep enough to prevent captured animals from jumping out, and almost certainly need metal liners to prevent them climbing out. In most situations on the island it is far too time-consuming to dig holes sufficiently deep by hand. The use of drift fences in conjunction with the pitfalls themselves generally improves the efficiency of this trapping method. These were used in the pitfall lines used in the survey but metal ones seem necessary to prevent damage by crabs.

Species in the genus *Crocidura* are known as musk shrews, because they possess glands which emit a strong, musky odour, possibly to deter predators. Corbet and Southern (1977) reported that *Crocidura* spp in Britain are sometimes killed by cats, but are not a preferred prey, presumably because of the disagreeable odour. Thus, it may be that cats would not eat shrews on Christmas Island for this reason, or would do so only under conditions of severe food shortage. A more likely predator of shrews on the island may be the hawk-owl, *Ninox squamipila*. Owls are reported as major predators of shrews by many workers in many different countries (for example, Meester, 1963; Harrison, 1964; Hoekstra 1986; Happold & Happold, 1986). Birds, generally, do not have a very well developed sense of smell, so probably are not inhibited from eating musk shrews because of their odour.

Despite these findings, previous studies of the diet of *Ninox* on Christmas Island have not found any evidence of them eating shrews, or indeed any mammals at all. Andrews (1900) described the owl's diet as consisting of '...lizards, locusts, white-eyes, and perhaps rats', but it is not known how many individuals he examined. Gibson-Hill (1947b) examined the stomach contents of seven owls and reported that 'The owl feeds chiefly on large insects, and to a lesser extent on lizards and white-eyes.' Kent and Boles (1984) found that the gut contents of three owls examined by them consisted of one gecko and the rest insects. This does not mean that owls do not eat shrews, but it probably indicates that many owls or owl pellets would need to be examined to be certain of this. It may simply be a reflection of the fact that shrews are very uncommon, but the absence of any small mammals eg *Rattus* or *Mus*, suggests that *Ninox* on Christmas Island does not prey much, if at all, on this group of animals. Mice are common enough to be eaten by 27% of the feral cat population, but one needs to be careful in extrapolating to owls, because mice seem to be restricted to regrowth vegetation, whereas owls are found primarily in forest.

Efforts were made to catch owls early on in the survey, but they were unsuccessful. It seems likely however that methods could be developed to catch them, hold them in captivity for a time and collect regurgitated pellets from them without injury. Such a study would be best done as part of a separate investigation into the ecology of the owl itself. The diagnostic information provided in this report on the hair of mammals on the island could be used to identify any mammalian prey species encountered. Hair-tubes (Scotts & Craig, 1988) may be another way of establishing the presence of shrews, but hair-tubes require baiting, whereas pitfall traps do not. In the present study traps were baited with aromatic cheese, going on the information provided by Harrison (1964) but there is no guarantee that *C. attenuata* would find this bait attractive. It was found essential to rebait traps on a daily basis to replenish bait removed by ants. Hair-tubes would need to be rebaited daily for them to be effective. although it may be possible to use an additive to the bait to repel ants as described by Anderson and Ohmart (1977).

The causal factors responsible for the decline of shrews on Christmas Island are difficult to determine. Rats are thought to be predators of shrews on the Scilly Isles (Corbet and Southern, 1977) and on the Galapagos Islands *R. rattus* has been implicated in the extinction of endemic cricetine rodents (Brosset, 1963). However, it is clear from the fact that two shrews were caught in 1984/5 that rats had not completely displaced shrews at that time, although they could have been responsible for a reduction in their numbers. This, though, seems unlikely in view of the coexistence of shrews and the omnivorous *Rattus macleari* before settlement and the fact that Andrews (1909) found that shrew numbers had radically declined before *R. rattus* had penetrated much beyond the settlement area.

Could it be that the rat-crab relationship was disrupted, leading to greater numbers of crabs, which then caused a decline in the shrew population? Until areas with shrew populations are found, and the differences between these and areas where there are no shrews can be assessed, it is not possible to answer this question. From a qualitative examination of the capture sites of the 1984 and 1985 animals there does not seem to be a less dense crab population, nor any other obvious difference which would explain why shrews were found there when they seemed to have vanished from the rest of the island. Ecological information on *Crocidura attenuata* from elsewhere in its geographic range (see Jenkins, 1976; 1982) would be helpful, but this does not appear to exist.

Thus, the question of whether or not *C. attenuata* is still present on the island cannot be resolved at the present time, although there seems little doubt that it warrants the status of locally endangered. Even though the same species is present on Java (Jenkins, 1982), the likelihood of recolonisation in the short term is exceedingly remote, even if the causal factors which have led to its decline on Christmas Island were to be reversed. Heaney (1986) studied colonisation rates by small mammals between islands and estimated that successful colonisations happened only once every 250,000 to 500,000 years, even when the islands were only 15 km apart. The chances of a small mammal rafting across the 360 km water gap, which separates Christmas Island and Java, and establishing a breeding population, seem low indeed.

Nevertheless, such an event must have occurred at some time in the past, and under conditions similar to those of the present day. The palaeo maps show virtually no difference between 20,000 BP and now, so far as the southern coast of

Java and Christmas Island are concerned, although Christmas Island may have been a little larger, due to lowered sea levels. The closure of the Arafura Sea and the joining of Java to Malaysia and Borneo may have strengthened the equatorial current flowing westwards and diverging southwest from NW Australia. No different from today really. Palaeoclimates were drier in Java and Sulawesi and northern Australia after 40,000 BP. Hence migration conditions have probably been largely unaffected over the last 200,000 years or so (Pigram and Panggabean, 1984; Audley Charles et al, 1988;).

Christmas Island burrowing rat, *Rattus nativitatis* and Maclear's rat, *R. macleari*

Have any other *Rattus* become extinct elsewhere in the world. IUCN Red Book ??

Of the five mammals originally present on the island, *R. nativitatis* seems to have been the least common and the least widespread. Andrews (1900) recorded that in 1897 'the bulldog rat....though very numerous in places, especially on the hills....is very much less common than *M. macleari*.' He added that animals had also been seen near the settlement, although he had seen none there himself (Lister, 1888 shot two on the shore in Flying-fish Cove). Andrews' observations on the distribution of the species are in accord with what one would expect of an animal so strongly modified for burrowing; soil deep enough to allow extensive burrows is present mainly on the plateau of the island. Andrews noted that occasional small colonies of *R. nativitatis* were also found in the fallen and hollowed-out trunks of the palm, *Arenga listeri*. One wonders how they managed to escape the attentions of *Birgus latro*, for these places are also frequented by these crabs. *R. nativitatis*, a non-climbing species, was thought by Andrews to feed on wild fruits, young shoots and perhaps the bark of trees. It apparently fared well on this diet, for subcutaneous fat deposits up to 19 mm thick were found on the dorsal surface of most animals. It was nocturnal, and if exposed to daylight, appeared half-dazed.

R. macleari was a very different species of rat, both in behaviour and distribution. In Andrews (1900) we find 'This species is by far the commonest of the mammals found in the island; in every part I visited, it occurred in swarms. During the day nothing is to be seen of it, but soon after sunset numbers may be seen running about in all directions, and the whole forest is filled with its peculiar querulous squeaking and the noise of frequent fights.' *R. macleari*, unlike *R. nativitatis*, was a good climber, which would contest the possession of fruit in trees with flying-foxes. It was also a nuisance because it ate skins and leather boots. It was clearly a much more active, aggressive animal than its congener, catholic in its tastes, and quite opportunistic in its choice of resting places. The picture that emerges is of a species not unlike *R. rattus* , but considerably larger (head and body length up to 240 mm), and with a large, powerful skull and dentition.

Andrews, no doubt, was rather surprised when he returned to the island in 1908 to find that both native species of rats had completely disappeared, although with typical British aplomb, he did not emote. His explanation for the disappearance of the rats due to the advent of a rat pathogen seems plausible, although it seems probable that more than one pathogen would need to have been involved to have caused the complete eradication of both species (restricted gene pool). He noted one consequence of the disappearance of the native *Rattus*: 'In other parts of the island clearings are often occupied by great numbers of seedlings of *Inocarpus* *edulis*; this is one of the consequences of the extinction of the rats, which formerly fed largely on the fallen fruits of this tree' (Andrews, 1909b). There may have been others.

It seems possible that *R. macleari* was a predator of crabs and if so, the large numbers of rats could have had a major regulatory effect on crab populations. A phenomenon known as "attack autotomy" has been described in some species of land crabs and is thought to be a response to mammalian predators (Robinson et al, 1970). The red crab, *Gecardoidea natalis* exhibits this behaviour (H. Yorkston, unpublished observations) and it may be that it evolved in response to predation by *R. macleari*. Certainly prior to settlement there was no other mammalian predator present. Some species of rats, for example *Xeromys myoides* in Australia are known to be major predators of crabs (Watts and Aslin, 1981). Another piece of circumstantial evidence, possibly related, is the statement by Andrews (1909a), that the robber crab, *Birgus latro*, was largely diurnal in its habits. This could explain why he did not comment on disturbance of mammal traps by crabs, a major problem experienced in implementing the present study (see discussion of *R. rattus*). Both the native rats had been strictly nocturnal. One cannot imagine a rat successfully preying on large robber crabs, but large crabs do not start life at that size. It is, unfortunately, not possible now to test these ideas, but they make for interesting speculation, nonetheless. Without postulating some radical change in the relative numbers of rats and crabs from the situation now it is difficult to reconcile all the available evidence, circumstantial though it is, about the status quo at the time of settlement.

The only trace of native rats found during the present study was the recovery of sub-fossil remains of *R. macleari* from small limestone fissures and caves about mid-way between trap lines 15 and 29. The original deposit of this material was located by H. Yorkston and J. Tranter in 1987??, but a second deposit was located by A. Russack during the 1988 survey. Remains from a number of individual *R. macleari* have been isolated from this material and these have been deposited in the Western Australian Museum, Perth. This is probably the only material of *R. macleari* in existence outside the British Museum of Natural History, which holds the specimens collected by Andrews in 1887 and previous collectors on the island. There does not seem much doubt that both species have been extinct for some time and therefore qualify for the 'extinct' category of IUCN (1988). They are not presently listed in this document.

Black Rat *Rattus rattus*

Rattus rattus seems to be the only rat now present on Christmas Island and it occurs in all vegetation types, except perhaps marginal rainforest, although it is nowhere in what would be described as great numbers.. It was found in highest numbers in the coastal fringe of *Scaevola* dominated vegetation, which may be because it has access to scavenged food from the shoreline or it may be because of other factors (see later in this section). *R. rattus* also occurred in relatively high numbers in regrowth vegetation. In this vegetation the exotic plant, *Muntingia calabura*, probably provides a staple food source for *Rattus*, as it appears to do for *Pteropus* and the Imperial Pigeon, *Ducula* , both of which can also be commonly seen feeding on its fruit. In regrowth areas at night it was common to see *R. rattus* in the branches of these trees. No doubt, in the wet season the patterns of rat distribution may change somewhat, but the critical time of year for all species is probably during the dry season, when water and food availability are both low.

R. rattus seems to have been present on the island since shortly after human settlement (Andrews, 1909) and it is now certainly well established. It is common enough to form an important part of the diet of feral cats (30.5% by weight; 53% by occurrence) and almost certainly feral cats are partly responsible for stabilising rat numbers. In New Zealand forests *R. rattus* is eaten by a similar percentage of feral cats (Fitzgerald and Karl, 1979) and it has been demonstrated in this situation that if cat numbers become depressed due to other factors, rat numbers increase markedly (Newsome, 1990).

Circumstantial evidence suggests, quite strongly, that there have been marked fluctuations in rat numbers since the species first colonised the island. The low numbers of rats on the island now seem to be in marked contrast to the description of circumstances in the 1930s, when local residents would take their dogs ratting at the 'rat patch' (Neale, 1988). In the late 1930's Gibson-Hill (1947a) apparently had no difficulty in collecting more than 200 rats, whereas in 1988 a total of over 2000 trap nights yielded less than 50 rats. This was only after a great deal of effort had been expended in excluding crabs. It is significant to note also that Andrews did not comment on the problem either (Andrews, 1900; 1909b). It seems difficult to put this down merely to British aplomb and the conclusion that the relative numbers of rats and crabs have changed seems inescapable. Certainly Storer (1962) and Wodzicki (1968) had great difficulty in trapping small mammals on islands in the Pacific Ocean, because land crabs (*Coenobita* and *Birgus*) set off all the traps before the rats had a chance to do so.

It seems possible that predation on nestlings by robber crabs would also be a significant factor in keeping rat numbers low and competition for food with both robber crabs and red crabs may further restrict rat numbers. Yaldwyn and Wodzicki (1979) surmised that land crabs on the Tokelau Islands affected *R. exulans* in similar ways. On Christmas Island the speed with which animal protein, such as cat carcases, is broken down by robber crabs, and the amazingly bare forest floor, kept almost totally clear of fallen organic matter by red crabs, testify to the pivotal role these crustaceans play in the island ecosystem.

There is much evidence (summarised by Atkinson, 1985) to show that rats can be important predators of birds and Stokes (1988) surmised that these species were implicated in the decline of various species of birds on Christmas Island. Stomach contents of *R. rattus* were not examined in the present study, but even if rats were implicated as predators of native vertebrates, it is a daunting thought to contemplate a control programme for rats on the island. Not least of the problems would be avoiding direct or secondary poisoning of land crabs as found by Smith (1969) on the Gilbert and Ellice Islands and Wodzicki (1973) on the Tokelau Islands. The largest island from which rats have been eradicated that we are aware of is Otata Island of 22 ha (Moors, 1985). Christmas Island is over 600 times this size.

A few more or less hairless rats have been observed on Christmas Island from time to time (H. Yorkston, unpublished observations) and it may be that this is due to the ingestion of the mimosine-containing seeds of *Leucaena* or *Mimosa* , both of which are common in regrowth areas. Mimosine can inhibit reproduction as well as cause hair loss (Crounse et al. 1962; Joshi, 1968), although, in the normal course of events one would expect that a specific aversion to the ingestion of poisonous substances would be set up (Milgram et al. 1976). Perhaps in unusually severe periods of food shortage rats ingest *Leucaena* or *Mimosa* seeds to their detriment.

House Mouse, *Mus musculus*

A similar situation to that in *R. rattus* exists (Yosida, 1980) with *Mus musculus* (Capanna, 1982), but without the remarkable variation in external appearance exhibited by its larger relative. What is the specific identity of the *Mus* present here?

From the trapping data one would infer that mice were neither widespread, nor common on Christmas Island as this species was trapped at only two locations. However, sixteen of the cats examined in 1988 contained mice in their guts and these came from widely separated locations on the island (Figure 9). Of the sixteen, all but one cat was shot in regrowth vegetation and the other one was killed less than 500 m from the nearest patch of it. Two conclusions follow: firstly that cats are more effective at catching small mammals than traps are, and secondly that mice are fairly widely distributed on the island, but are almost certainly restricted to regrowth. Although one cannot be certain that a cat which has a mouse in its gut has caught it at the place at which the cat is shot, it seems reasonable to assume that it has probably not caught it far away. Rate of passage?? After a plague, trapping failed to produce evidence of *R. villosissimus* in tropical grasslands in Australia, yet 40% of dingoes in the area were still eating them (Newsome and Corbet, 1975). Gibson-Hill (1947a) reported mice only in the settlement area, but it may well be that the species was more widespread than he thought. He does not give details of the trapping procedures he used, so it is not possible to determine their reliability.

Brown Rat, *Rattus norvegicus* and Polynesian Rat, *R. exulans.*

The evidence that either of these species was present on the island (summarised in the introduction) is conflicting and we are inclined to believe that they never were. Chasen (1940), in his discussion of mammals of the Malaysian region, recorded neither *R. norvegicus* nor *R. exulans* from Christmas Island. He noted that *R. norvegicus* was usually restricted to settlement areas and was rarely found in the surrounding country. *R. norvegicus* needs access to free water, unlike *R. rattus* (Corbet and Southern, 1977; Watts and Aslin, 1981), so that it is most unlikely to be able to survive the dry season on Christmas Island, except in the vicinity of freshwater seepages, which are hardly of sufficient extent to sustain large enough reservoir populations. Traplines in these areas caught only *R. rattus*. It does not now seem possible to completely resolve the conundrum. Neither the Raffles Museum (now the National Museum of Singapore) nor the British Museum of Natural History holds any specimens of *R. exulans* or *R. norvegicus* from Christmas Island (C.M. Yang, *in litt.*; P.D. Jenkins, *in litt.*).

One possible explanation for Gibson-Hill thinking that he had trapped *R. norvegicus* and *R. exulans* on the island may be the extraordinary variability in the appearance of *R. rattus*. This has caused much confusion in the past and Wood-Jones (1925) pointed out that the species had been described under nine different names in Australia alone. It is now known that there are several different chromosome races of *R. rattus*, and these may be reproductively isolated to some extent (Yosida, 1980). Another possible explanation, although not one we believe to be the correct one, is that *Rattus norvegicus* and *R. exulans* were, in fact, present on the island at the time of Gibson-Hills's survey, but have since become extinct.

Certainly neither *R. norvegicus* nor *R. exulans* was trapped in 1988 and no fur from either was found in cat guts. However, *R. norvegicus* may not be a preferred food of cats, even if it is readily available.. On Raoul Island, in the Kermadec Group, both *R. exulans* and *R. norvegicus* are present and more *R. norvegicus* than *R. exulans* are caught in traps, but very few *R. norvegicus* are eaten by them. This may be a reflection of the large size and aggressive behaviour of Norway rats (B.M. Fitzgerald, in litt. what about young ones? they might not taste nice). Whatever the case, it seems highly unlikely that either *R. norvegicus* or *R. exulans* occurs on Christmas Island now. If they are present then they are not so in very great numbers, or one assumes that they would have been found by trapping, through cat diet analysis, or through people trapping them in the settlement. It is possible, of course, that they could be inadvertently introduced in the future and become established, although given the ascendancy of *R. rattus* now and the shortage of free water, this seems rather unlikely. However, on some islands in the western Indian Ocean *R. rattus* and *R. norvegicus* occur together and on many in the Pacific Ocean, all three commensal rodents are present (Atkinson, 1985).

Feral cats *Felis catus*

Cat distribution and numbers

In other areas the density of cats is known to range from more than 300 km^{2-1} (UFAW, 1981) to less than one km^{2-1} (Jones and Coman, 1982). Cat density is not purely a response to resource availability as was demonstrated by Konecny (1987) who studied two populations of cats on the Galapagos Islands, one with better access to prey than the other. He found that population densities were essentially similar in both areas, but in the poorer site territoriality was more rigorously enforced. Line transect procedures can be used to establish absolute densities of animals, even if visibility varies (Morgan, 1986), but this was not attempted in the present case.

Data derived in this study can be used to show little more than rough indications of relative abundance, bearing in mind that no correction has been made for differing visibility in different vegetation types. The main point to be drawn from the data is that cats are much more common in regrowth vegetation than in natural vegetation and this conclusion is corroborated by the finding that it is in regrowth vegetation that cats catch most of their food. Taken together, rats, flying-foxes and imperial pigeons comprised 83.5% by weight of feral cat diet. All of these species can be caught with relative ease in regrowth vegetation, particularly where *Muntingia* is abundant. *Pteropus* and *Ducula* would both be difficult for cats to catch in other areas because they feed high in the canopy. Even though cats are skillful climbers they probably do most of their hunting on the ground as Catling (1988) found of cats in a semi-arid woodland area of Australia. *Rattus* is also common in regrowth vegetation and uncommon in forest.

The other vegetation type in which cats may be common is the coastal fringe of *Scaevola*. *R. rattus* was found to be common here and it is in and around this vegetation that many seabirds nest. *Scaevola* was not surveyed for cats in this study because there is no vehicular access, and moving through it on foot at night is both difficult and hazardous. At certain times of the year it might be possible to survey this vegetation by spotlight from a boat. No seabirds at all were found in any of the cat guts examined, but this may be because few of the cats examined were taken from near the coastline, which is where the substrate nesting species breed. Seabirds most at risk from cat predation on Christmas Island, because of their nesting sites are the Brown booby, *Sula leucogaster*, the Red-tailed tropicbird, *Phaethon rubricauda* and the Common Noddy, *Anous stolidus* (Stokes, 1988). Fitzgerald (1988) recorded that seabirds comprised a large proportion of the species of birds eaten by feral cats on many islands, particularly small oceanic islands. Hugh, when do these species breed??

Yorkston (1981) reported a total of 60 kills and sightings in 440km, giving an average rate of 13 cats per 100 km. However, Yorkston did nearly all his collecting in the daytime, which would easily explain the difference from the present study, when 30 per 100 km were killed and sighted. Both studies were carried out during the dry season, although the 1981 survey was carried out late in the dry season, ie at a time when one would expect food availability to be very low, whereas the 1988 survey was made earlier on in an unusually wet dry season, when food availability was probably higher. However, the proportion of juveniles in both samples was similar. Of the 17 animals collected by Yorkston for which data are available, three were less than 1.5 kg (17.5%) and of the 68 collected in this study, 14 were 1.5 kg or less (20.5%). On the Kerguelen Archipelago most kittens die before reaching maturity (Pascal,1980), and the very poor condition of most of the immatures in this study suggest that the dry season on Christmas Island is also a time of high juvenile mortality.

Cat diet and impact on other fauna

It is clear from the dietary analyses that cats eat native fauna, although one cannot be sure about what the overall effect is, in the absence of absolute density information of either cats, or native fauna. It would not be a difficult exercise to get absolute density information for cats, using radial distance measurements on transects, but there is little information available on absolute densities of species which are preyed upon by cats, so that overall effects are impossible to determine by this approach.

What is more useful is to consider the relative densities of prey species over time. Are they waxing, waning or remaining stable? The endemic gecko, *Cyrtodactylus* sp. nov., is high on the list of native species eaten by cats, yet Cogger et al (1983) reported that it was common, and it was also seen in large numbers in the forest at night during the present study. The same applies to most of the other lizards eaten by cats, the flying-fox, and perhaps the birds. Stokes (1988) listed a number of species which had undergone a decline in numbers since settlement, and cited cats (and possibly rats) as contributory factors. However, documented evidence for this is lacking. That cats eat birds is indisputable, but they appear by choice to be eaters of small mammals (Fitzgerald, 1988). Cats are facultative predators, so that prey species in low numbers are unlikely to become preferred food, unless they have been in plentiful supply earlier on (Newsome, 1990). What one can be certain about is that the native species still present have had to contend with the presence of feral cats for a long time. The only mammals which have exhibited a drastic decline are the two native rats and the shrew. There does not seem to be a direct link between cats and the demise of these species, and for reasons discussed earlier it seems rather unlikely that shrews would be a preferred food item of cats anyway. It may be that the presence of cats is not all bad, for they must exert a regulatory effect on the rat and mouse populations, which if uncontained, could lead to serious problems (Atkinson, 1985).

Possibilities for managing the mammal fauna

The island fauna has now contended with the presence of *Rattus* , *Felis* and *Mus* since shortly after settlement, yet no species seems to have become extinct or endangered as a result, with the exception of the two native *Rattus* and *Crocidura*, both of which declined very early on. Eliminating rats completely from the island would almost certainly be impossible, and probably unnecessary from a conservation/ management point of view. Smith (1969) and Wodzicki (1973) have made recommendations for the control of rats in areas with dense populations of land-crabs and it is possible that these could be implemented on Christmas Island. In the absence of a clearly demonstrable benefit from such a programme there seems little point in embarking on what would undoubtedly be a costly exercise and one which would need to be repeated at frequent intervals for it to have much effect. Removal of rats would probably also cause the cats to turn to other prey, and an integrated pest control programme would be mandatory (see Newsome, 1990). On the other hand, it seems likely that if degraded areas were to be revegetated that the numbers of rats would diminish, although this may not have much effect on the coastal *Scaevola*. *Mus* would become a scarce species if cleared areas could be revegetated.

The likelihood of eradicating feral cats from Christmas Island seems remote and reducing the population would also be difficult. The exact number of cats on the island is unknown, but there was no noticeable diminution in numbers seen on transects after 57 cats had been removed at a cost of 113 man hours effort. Van Rensburg and Bester (1988) were able to reduce cat numbers on a small island by hunting when the population was already reduced by environmental factors, but on Christmas Island shooting seems unlikely to have a significant effect, unless it could be carried out over a very long period. Indeed the removal of a few animals in this way is more likely to promote the survival of the remainder by reducing competition for food. UFAW (1981) concluded that the removal of feral cats from their place of abode was detrimental to cat control because other animals soon moved in to take up the space. They advocated neutering cats and returning them to the population. This possibility, also, seems unrealistic for it would be almost impossible to trap cats on the island, because of the prevalence of land crabs, which spring traps before target animals can get to them. Cats could, perhaps, be caught by treeing with dogs and then tranquilised as reported by Jones and Coman (1982b), but the cost in effort would be prohibitive. Removal of rats would probably also cause the cats to turn more to other prey, and an integrated pest control programme would be mandatory (see Newsome, 1990).

The only other active way of removing cats would be by poisoning them. Whilst this may be achievable, at least in part, the effects on non-target animals, eg crabs, would be quite undesirable. In any event, the presence of land crabs, again, would be problematical. Yaldwyn and Wodzicki (1979) described the problems experienced with trying to selectively poison rats in land-crab infested areas. With rats, at least, the target animal is smaller than the non-target animals, so that crab excluders can be used. With cats, however, one is dealing with a larger target animal so that it would be extremely difficult to devise a system which poisoned cats but not crabs. Perhaps with some research one could find a poison which acted on cats but not crabs (eg paracetamol), but two problems mitigate against the usefulness of any poisoning scheme, (1) cats by choice do not seem to eat much scavenged food (Fitzgerald, 1988; this study), (2) crabs would in most cases eat the bait before a cat had the opportunity to reach it.

Veitch (1985) discussed the use of feline enteritis to reduce cat populations, but concluded that islands were generally too small for the method to be effective, without the continual injection of new viral strains. At best, a temporary reduction in numbers could be expected, which may then result in subsequent irruptions. It has been suggested that cats should be removed from the settlement area on Christmas Island on the basis that this population acts as a reservoir to replenish the feral population. The evidence from the present study indicates that feral cats are well established on the island, have been for a long time and do not rely on replenishment from the settlement. Thus, in addition to the 'political' problems associated with cat destruction in populated areas, there seems little to be gained by opportunistic destruction of cats. The only way in which any real diminution of the cat population could be achieved without undesirable side effects is probably by revegetation of cleared areas. This would have the effect of drastically reducing the food availability, which in the long term could be expected to cause a decline in numbers not only of cats, but of rats and mice as well. A large-scale 'experiment' is now underway with the rehabilitation of cleared areas from royalties derived from the new mining operation. What effect would this have on *Pteropus* and *Ducula*?? Is hunting of *Pteropus* still permitted?? Perhaps the next hundred Christmases will bring more welcome gifts.

Acknowledgements

This study would be not have possible without the cooperation of many people, and to all of these we are extremely grateful. In particular, the Government Conservators on Christmas Island in 1984 and 1988, Tony Stokes and Dave Phillips, respectively, both provided essential logistical support, as did Graham Collins and Jane Yorkston. Peter Green gave up many of his nights to pursue cats instead of crabs and Graham Collins provided logistical support without which the survey could not have been completed. Jenkins/Yang/Kitchener fur etc. Barry Baker, John Clark, Peter Goh, John Hicks, Peter Jarvis, Giselle Nathan, Barry Reville, Geoff Rochfort, Holger Rumpff, Natalie Rutherford and Jeff Tranter all provided assistance in various ways. Barbara Triggs identified the fur samples for the analysis of cat diet and Alison Rowell identified the feathers. Mike Howell identified the gut parasites; Don Colless and Bruce Halliday identified the ectoparasites from *Pteropus*. Wrink Guppy identified the pollen. Lionel Hill sorted the *Pipistrellus* gut contents. Noel Call histology. Debbie Gawin computed the diagrams. Funding for the study was provided by the Australian National Parks and Wildlife Service as part of its research and surveys programme.

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(c) Hair structure

The following key should be used in conjunction with Appendix a and general descriptions provided by Brunner and Coman (1974).

1 (a) Medulla type wide aeriform lattice....................2
(b) Not as above....................6

2 (a) Cross-sectional shape concavo-convex....................3
(b) Not as above....................5

3 (a) Medulla large....................4
(b) Medulla bilobed....................*Rattus exulans*

4 (a) Maximum diameter of primary guard hair 240 µ....................*R. rattus*
(b) Maximum diameter of primary guard hair 50 µ....................*Mus*

5 (a) Many granules in cortex....................*R. nativitatis*
(b) Few granules in cortex....................*R. macleari*

6 (a) Medulla absent....................*Pteropus*
(b) Medulla present....................7

7 (a) Medulla type uniserial ladder....................*Crocidura*
(b) Medulla type wide coronal or wide lattice....................8

8 (a) Medulla type coronal....................*Pipistrellus*
(b) Medulla type wide lattice....................*Felis*

R. norvegicus; R. exulans

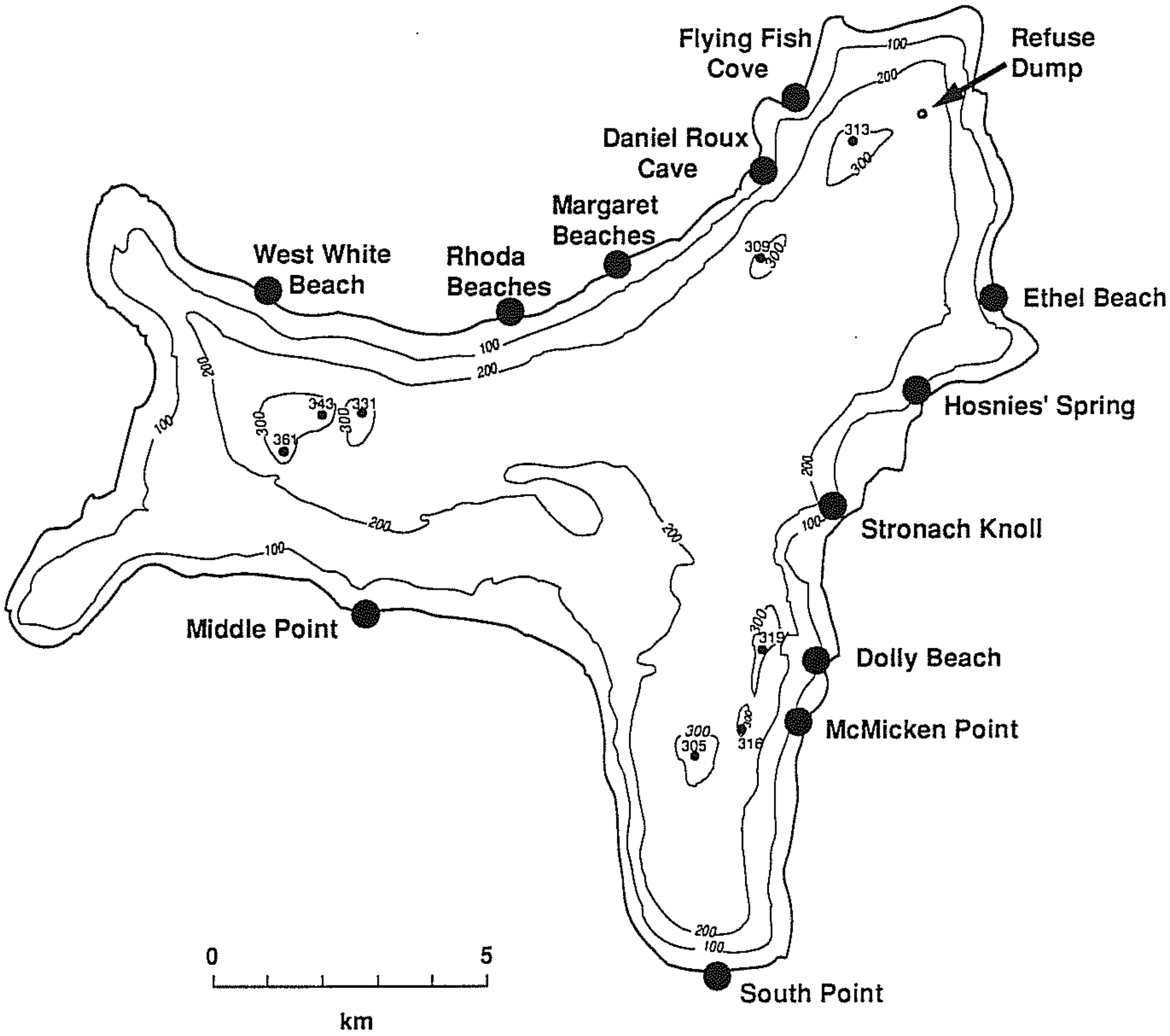


Figure 1.
Location of flying fox camps on Christmas Island.

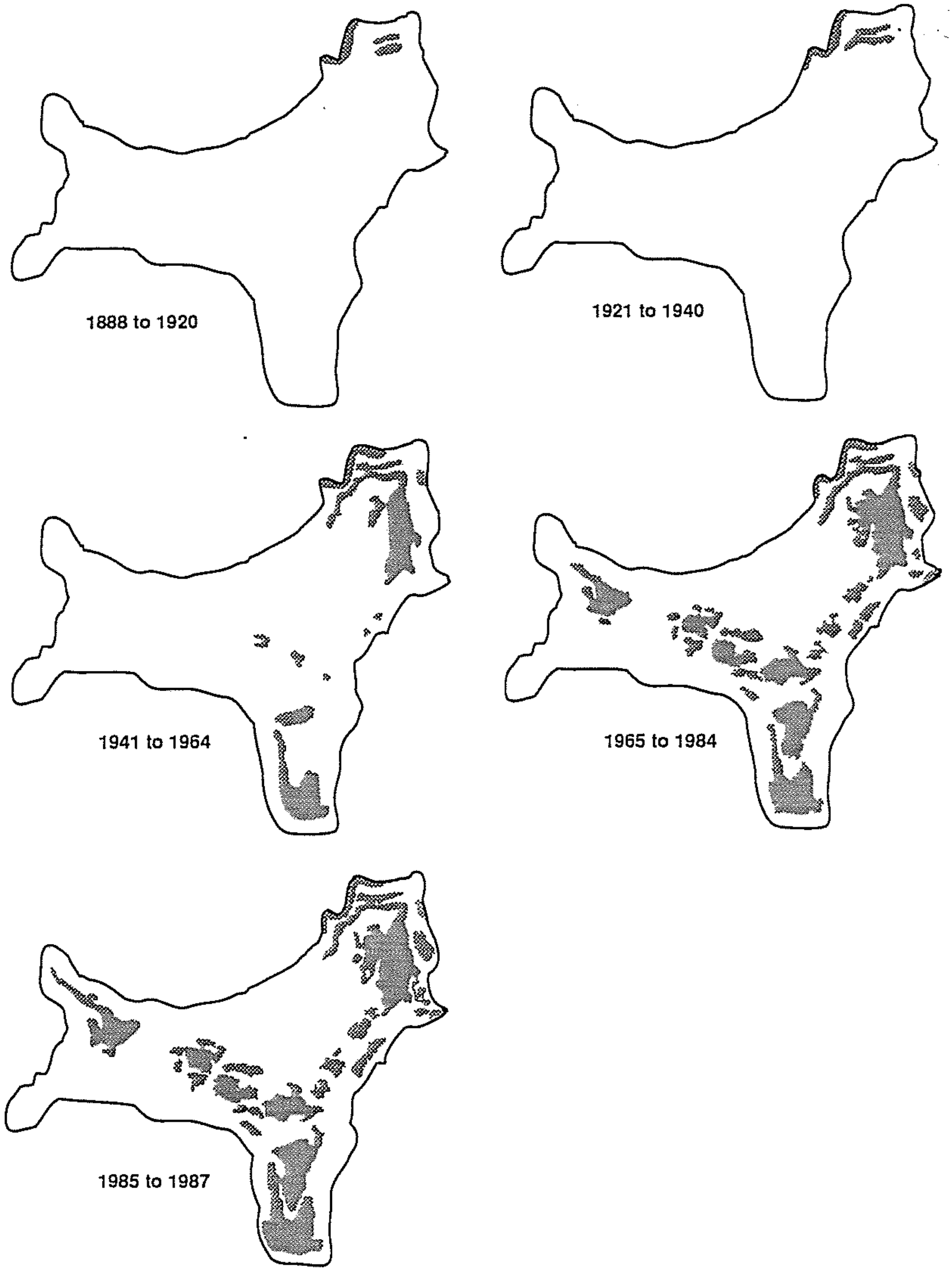


Figure 2. Clearing of natural vegetation on C.I.

Photocopy of original

These are being redrawn.

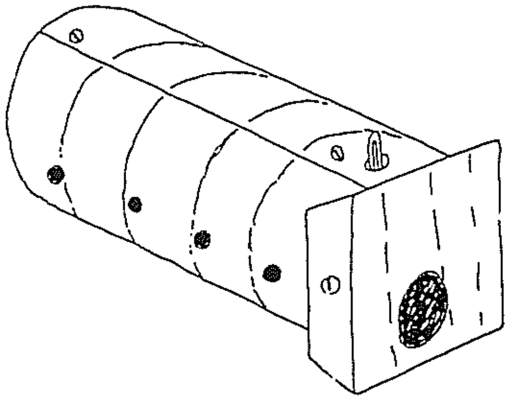


Figure ~~4~~ 3 (a) Crab excluder for setting snapback trap on the ground. The tube is butted up against a buttress root or rock and held in place with a large rock or log. This prevents entry of any animal which cannot fit through the 50 mm diameter entrance hole. Large crabs are prevented from getting their claws inside the structure by the presence of a baffle about 60 mm inside the entrance.

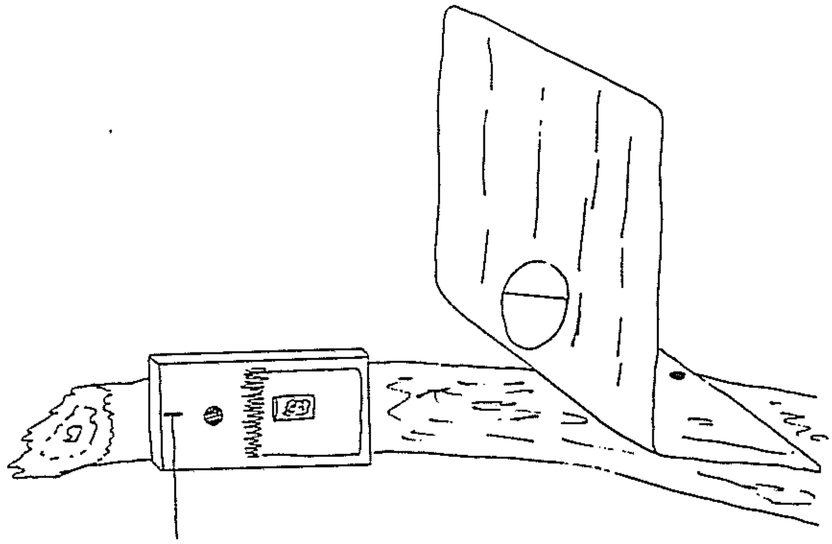


Figure ~~4~~ 3 (b) Crab excluder for setting snapback trap above the ground surface. The metal plate is nailed to a small branch cut for the purpose, and the trap is nailed in a vertical position on the side of the branch to minimise the risk of it being sprung by raindrops. The branch can then be elevated above the ground surface by placing it over a stump or rock. Crabs have great difficulty in reaching the trap, but small mammals are able to gain access through the 50 mm hole in the plate.

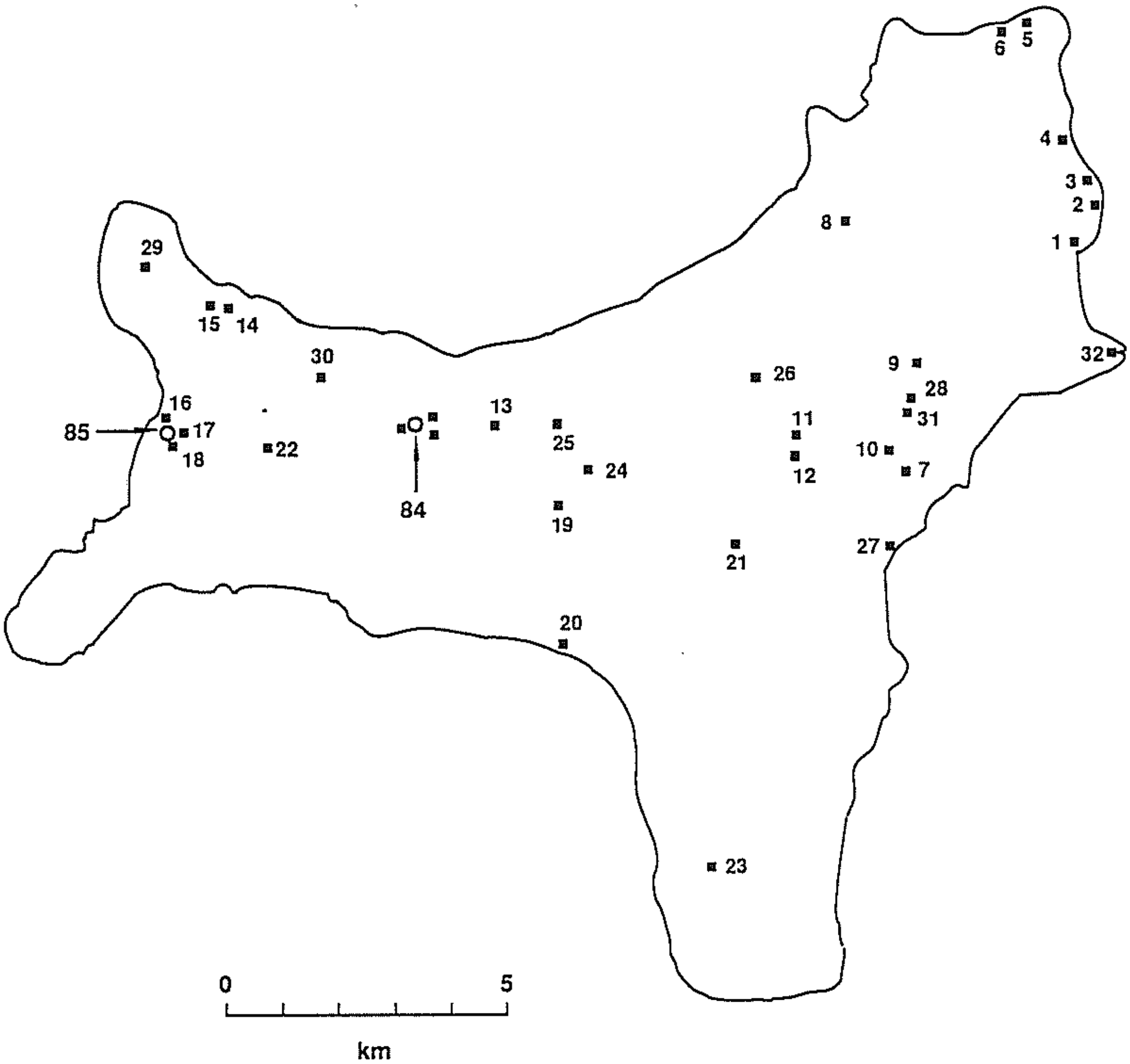


Figure 4. Traplines for small mammals. Circles show where shrews were caught in 1984 and 1985.

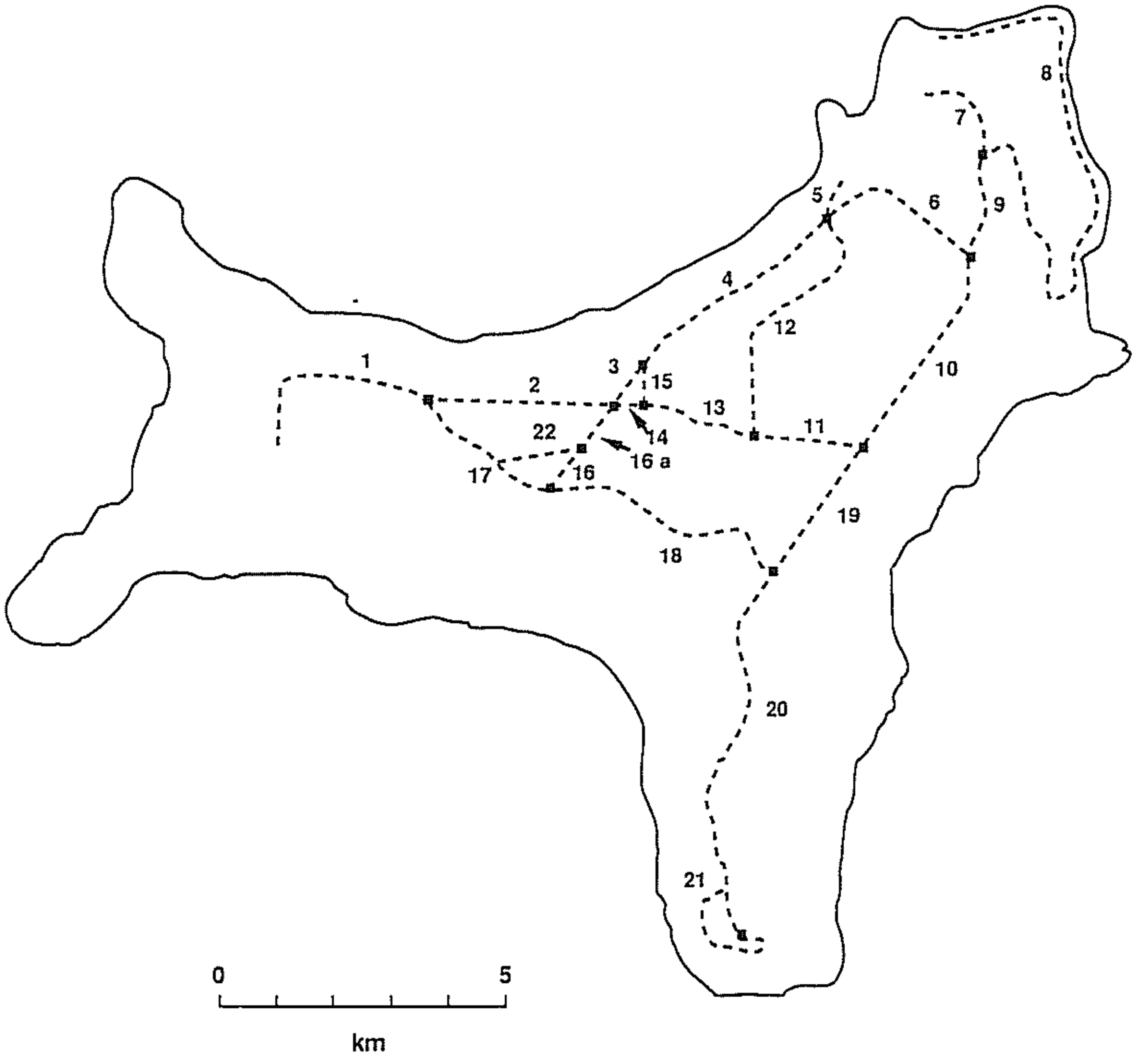


Figure 5. Spotlighting routes for cats.

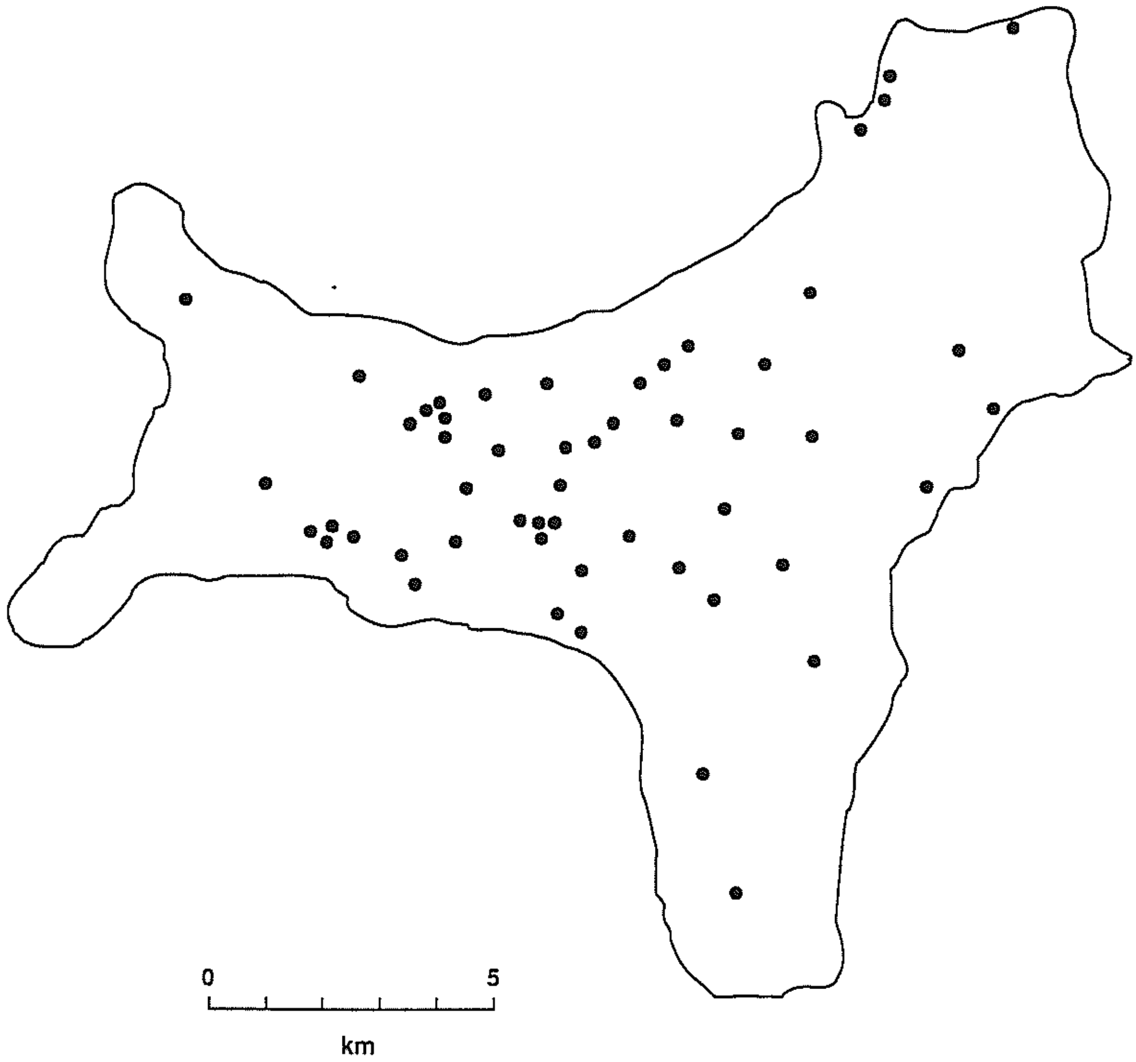
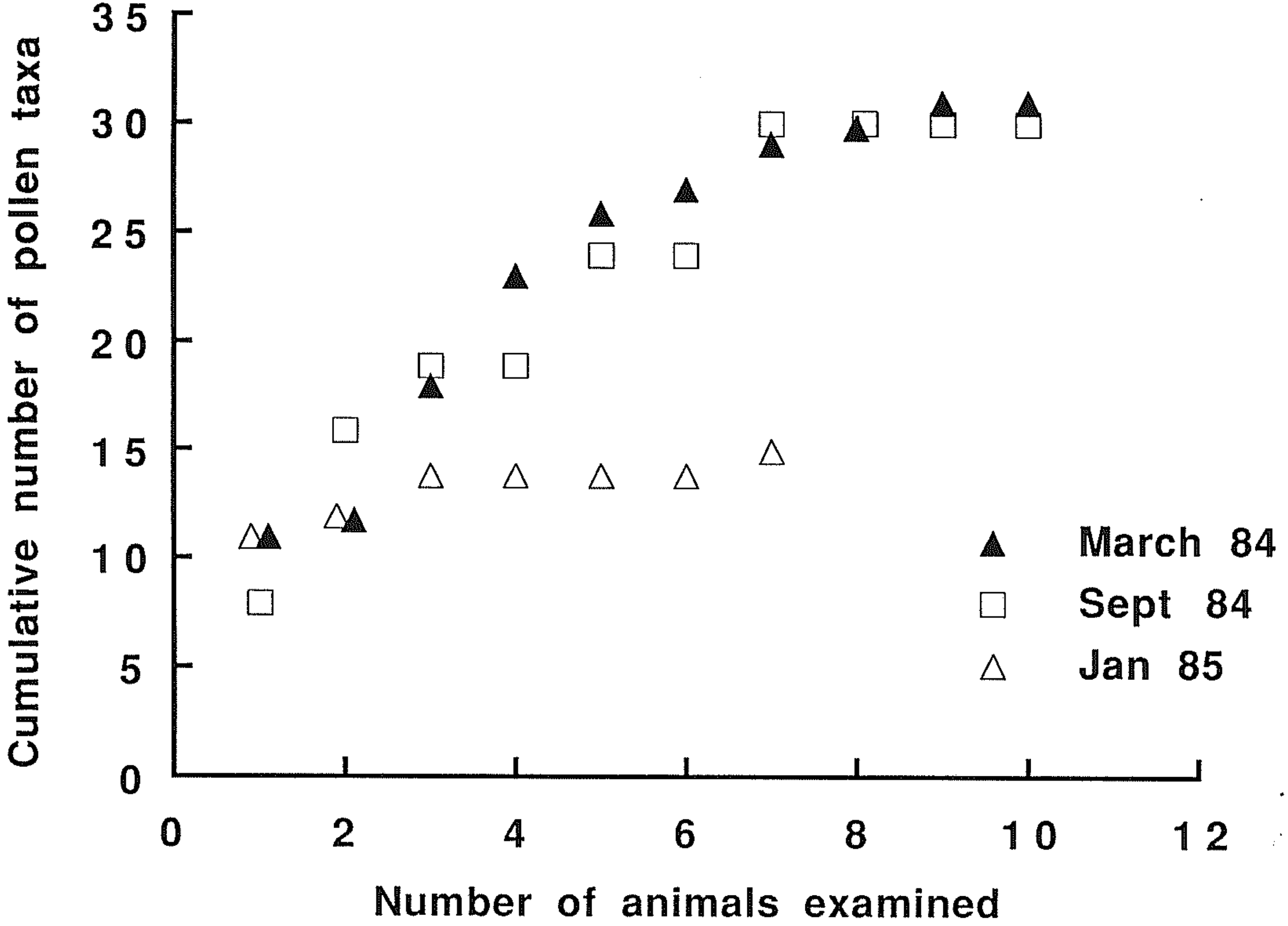


Figure 6. Sites at which *Pipistrellus murrayi* was recorded.


35
30
25
20
15
10
5
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2
4
6
8
10
12
Cumulative number of pollen taxa
Number of animals examined
March 84
Sept 84
Jan 85

Figure 7.

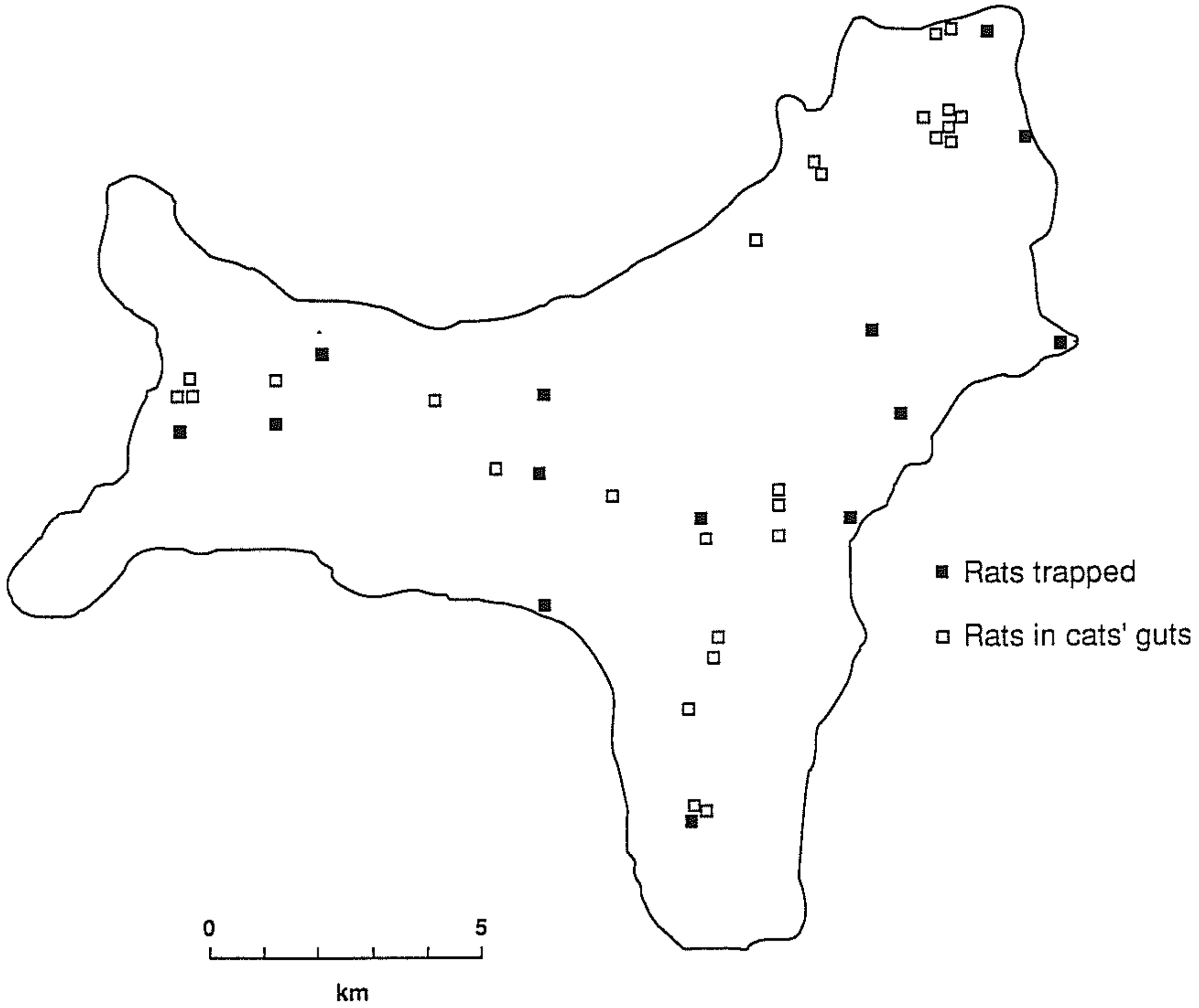

Figure 8. Sites at which Rattus rattus was trapped (solid squares) and identified in cat guts (open squares)

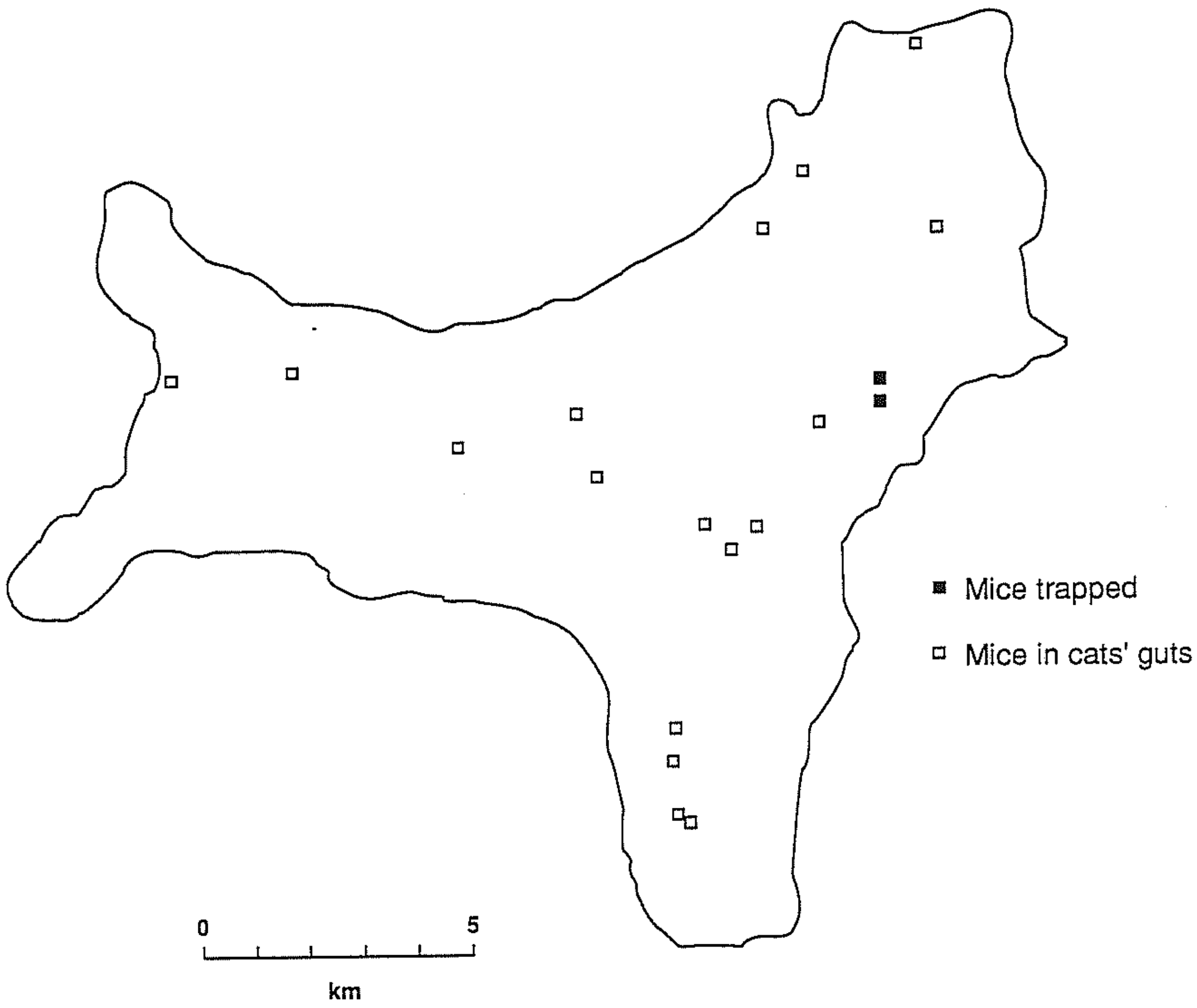

Figure 9. Sites at which *Mus* was trapped (solid squares) and identified in cat guts (open squares).

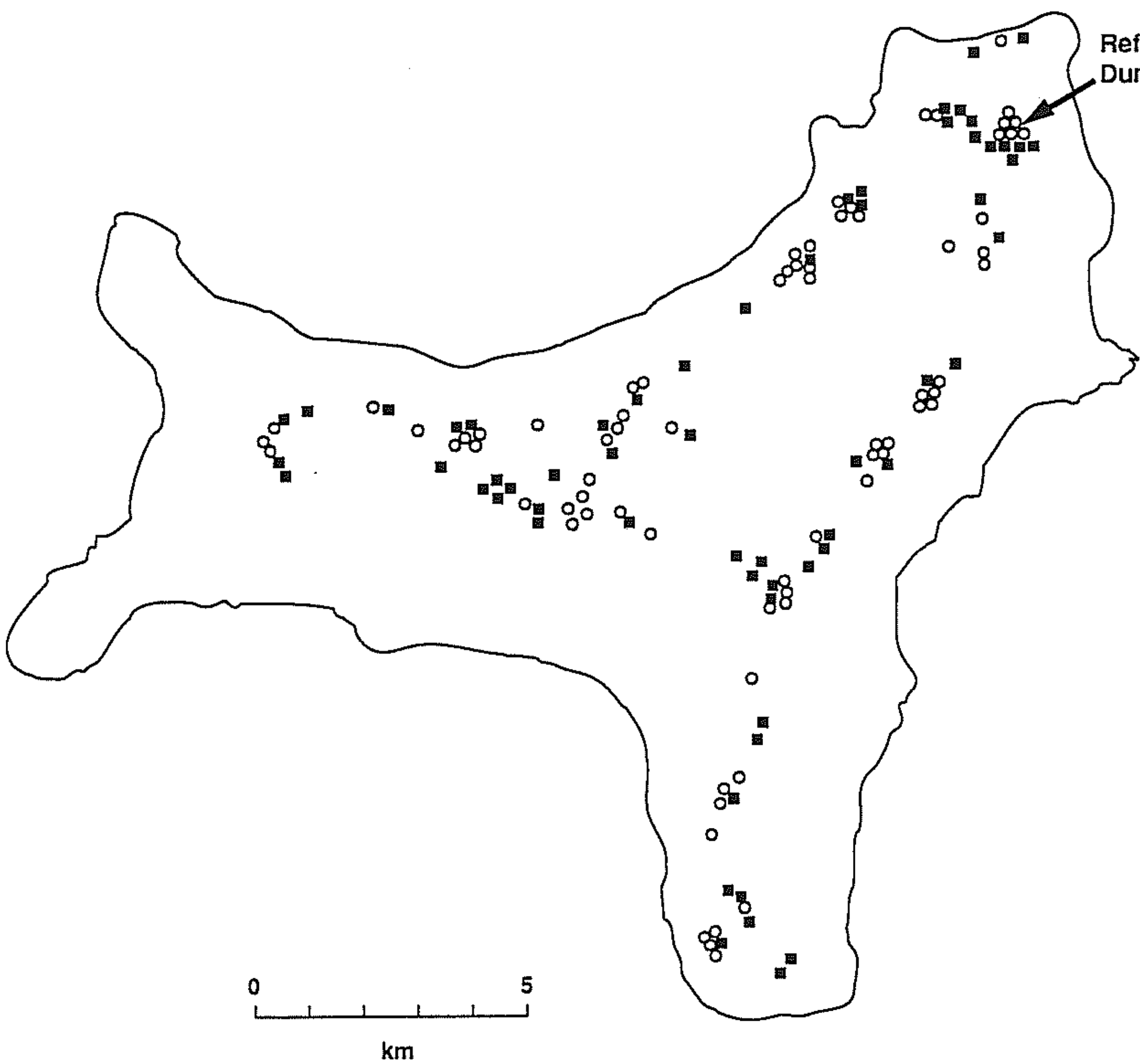

Figure 10. Sites at which feral cats were seen (open circles) and shot (solid squares)

TABLE 7.

Prey type	Mean body weight of prey	COMMENSAL (n=18) No. of guts with prey type	No. of prey individuals	% by occurrence	% by weight	FERAL (n=74) No. of guts with prey type	No. of prey individuals	% by occurrence	% by weight
Mammals									
Pteropus	350[1]	0	0	0	0	9	9	12	23
Rattus	108[1]	3	3	16.5	29	39	39	53	30.5
Mus	13[1]	4	4	22	4.5	20	24	27	2
Birds									
Ducula	524[2]	0	0	0	0	8	8	11	30
Chalcophaps	95[2]	0	0	0	0	3	3	3	2
Collocalia	5[2]	0	0	0	0	1	1	1.5	<.01
Turdus	44[2]	1	1	5.5	4	1	1	1.5	<1
Zosterops	10[2]	3	3	16.5	3	9	9	12	<1
Reptiles									
Cyrtodactylus	8[3]	0	0	0	0	19	57	25.5	3.5
Hemidactylus	3[3]	0	0	0	0	1	1	1.5	<.1
Emoia atrocostata	9[3]	0	0	0	0	1	1	1.5	<.1
E. nativitatis	5[3]	1	1	5.5	<1	5	9	7	<1
Lygosoma	1[3]	0	0	0	0	2	2	3	<.1
Cryptoblepharus	1[3]	0	0	0	0	2	2	3	<.1
Invertebrates									
Red crab	70[4]	9	9	50	56	9	9	12	4.5
Grasshopper	1.5[1]	5	20	27.5	2.5	42	240	57	2.5
Cicada	1[1]	2	6	11	<1	0	0	0	0
Cockroach	0.7[1]	0	0	0	0	3	3	4	<.1
Cricket	0.8[1]	0	0	0	0	5	15	7	<.1
Moth	2[1]	0	0	0	0	1	2	1.5	<.1
Carerpillar	0.9[1]	0	0	0	0	2	5	3	<.1
Mantis	1[1]	0	0	0	0	1	1	1.5	<.01
Spider	0.7[1]	0	0	0	0	1	1	1.5	<.01

Sources of information of mean body weights: [1]This study; [2]CSIRO National Wildlife Collection; [3]Cogger et al (1983); [4]Hicks (1985).