DIET AND COEXISTENCE OF *RATTUS RATTUS RATTUS* (LINNAEUS), *RATTUS EXULANS* (PEALE) AND *RATTUS NORVEGICUS* (BERKENHOUT) ON STEWART ISLAND, NEW ZEALAND

A thesis presented in partial fulfilment
of the requirements for the degree of

MASTER OF SCIENCE

in

ZOOLOGY

at

MASSEY UNIVERSITY

ANDREW TREVOR STURMER

1988

Abstract

Coexistence and diet of *Rattus rattus rattus, Rattus exulans* and *Rattus norvegicus* on Stewart Island was investigated by snap-trapping and stomach analysis. The trapping period was from June 1982 to December 1986. Four habitats were trapped for three nights every three months. Morphometric and reproductive information was collected throughout the programme. Studies of food availability, involving two forms of invertebrate sampling and plant phenology recordings, were undertaken in the final year of trapping.

Overall rat abundance was 4.0 rats/100 trap-nights which is comparable with other findings in mainland forests and on large offshore islands in New Zealand. *R. norvegicus* abundance was significantly lower than that of *R. rattus* and *R. exulans*. Species composition varied considerably between transects and a high degree of disassociation between *R. exulans* and *R. norvegicus* was recorded. *R. norvegicus* was restricted to areas very close to water. Seasonal variation in rat abundance was marked and was most affected by changes in *R. rattus* and *R. exulans* numbers. Highest rat abundance was in winter of each year.

Male *R. exulans* were heavier ($\bar{x} = 65.61$) than females ($\bar{x} = 60.77$) and the same was true for *R. norvegicus* (male $\bar{x} = 201.40$, female $\bar{x} = 165.50$). All rat species were smaller than those trapped previously from New Zealand. Few pregnant rats were trapped but seasonal breeding of *R. rattus* and *R. exulans* was suggested by annual increases in the proportions of juveniles in winter and spring.

Invertebrates and vegetation were the main foods eaten. In terms of frequency of occurrence and mean percentage volume, invertebrates were most important for *R. exulans* and *R. norvegicus*. For *R. rattus* invertebrates were also the most commonly eaten food but vegetation provided greatest volume of diet. Of the three species, *R. rattus* had a more varied diet and *R. exulans* was most reliant on invertebrates. Orthoptera, Opiliones, Chilopoda and Coleoptera were the invertebrates most frequently eaten by *R. rattus*, whereas Orthoptera, Araneida, Chilopoda and Terricolae were the most common in the diet of *R. exulans*. Decapoda (freshwater crayfish) were the most frequent diet item of *R. norvegicus*, and Opiliones, Othoptera, and Araneida were also common. Fruits, especially *Prumnopitys ferruginea*, and unidentified seeds and rhizomes were the more common plant foods eaten. A greater importance of leaf material than has been previously recorded is suggested in the diet of *R. rattus*. Birds were rarely eaten by *R. rattus* and *R. norvegicus* and not at all by *R. exulans*. Two instances of *R. norvegicus* having eaten lizards were recorded.

Diet overlap was considerable but significant species differences were found. Diet varied with season for each species and for *R.rattus* and *R. norvegicus* there was variation between transects.

Coexistence in the various habitats is discussed.

Acknowledgements

The production of this thesis would not have been possible without assistance and advice from a number of people. The New Zealand Wildlife Service (now incorporated into the Department of Conservation) allowed me to take over their rat trapping programme on Stewart Island. They provided much information as well as the rat stomachs they had collected from their trapping between June 1982 and February 1985. They also provided financial and logistical support for travel and field work for which I am grateful.

I would like to thank my supervisor Dr. John Skipworth whose comments and suggestions were always well received. Special thanks are due to Dr. Ian Henderson for his assistance and advice on the statistical analyses needed to interpret the data.

Dr. Phil Moors and Duncan Cunningham (Department of Conservation), who headed the Wildlife Service trapping study, provided helpful information and advice on rodent ecology. Duncan Cunningham also proof read and commented on the final draft for which I am most grateful.

Andy Grant (Department of Conservation) provided assistance with techniques needed for cuticle analysis. The use of the reference collection of plant cuticles that he produced was extremely helpful. I would also like to thank Dr. Ralph Powlesland (Department of Conservation) for his encouragement and advice throughout the project.

Comments and discussions with staff and senior students of the Botany and Zoology Department were often helpful. A special thanks goes to Ian McGee who accompanied me on the June 1986 trip.

Finally I would like to thank my family and friends for their support and interest shown throughout the study.

TABLE OF CONTENTS

List of Figures

Figure Page

17 Phenology continued

List of Tables

List of Plates

1
Introduction

1.1 Rats in New Zealand

The rodent fauna of New Zealand comprises four species of the family Muridae. There are three rat species (plate 1, p.2) ***Rattus rattus*** (Linnaeus) - the ship rat, black rat, bush rat or roof rat, ***Rattus norvegicus*** (Berkenhout) - the Norway rat, brown rat, sewer rat, water rat, or dump rat, ***Rattus exulans*** (Peale) - kiore or Polynesian rat, Maori rat, and ***Mus musculus***[1] the house mouse or field mouse.

All three species of rat were introduced to New Zealand by man. Kiore were brought to New Zealand either accidentally or as a food source by the Maori approximately 800 years ago, possibly arriving with the Great Fleet. Once widespread throughout the New Zealand mainland, kiore have disappeared from the North and South island with the exception of some areas of Fiordland, where at least one of the other rodent species is absent. Kiore now only occur there, on Stewart Island and on many offshore islands, especially in the north (Atkinson 1978, 1986, Moller and Craig 1987). The decline of kiore has been attributed to competitive replacement by one or more of the other rodent species (Meeson 1884, White 1897, Watson 1956, Williams 1973, Atkinson 1973, Taylor 1975, 1978). For further comment refer to section 1.2 (p. 5).

Kiore are the smallest of the three species of rat reaching weights of 130g in New Zealand (Atkinson 1978). Their fur is brown dorsally and white-tipped grey ventrally. Other identifying features include large ears, hind feet dorsally dark near the ankle with the rest of the foot pale and a thin dark tail either slightly longer or slightly shorter than the head and body length (Cunningham and Moors 1983). They are generally ground dwelling, although may be partly arboreal (Stead 1936, McCartney 1970). Kiore nest either underground in short unbranched burrows or in shrubs and trees. Although possessing limited swimming ability, kiore are not known to forage under water.

Norway rats were the first European introduced rat to become established and are believed to have been brought to New Zealand by Captain Cook and subsequent whalers and sealers in the 18th century (Atkinson 1973). This is the dominant rat of northern hemisphere temperate climates where it has been held responsible for limiting

---

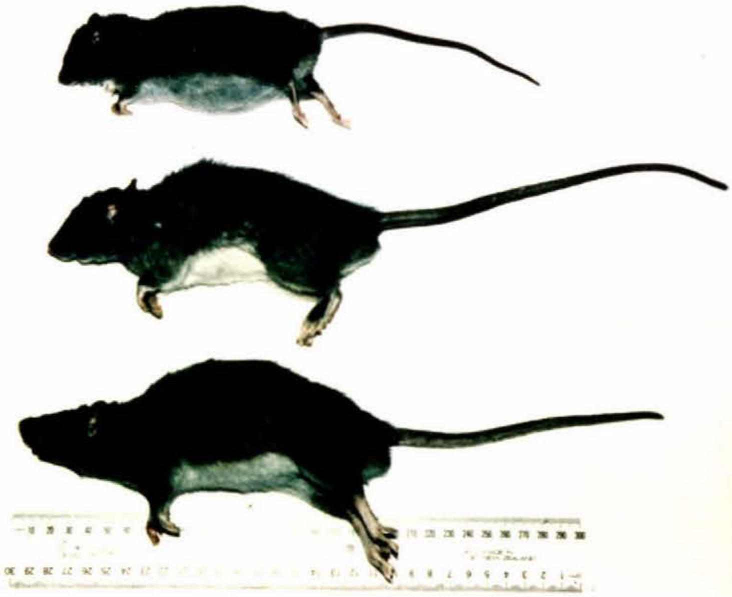
[1] Taxonomy of *Mus* in New Zealand is under revision; (WRLG Research Review 4, 1984)

PLATE 1: Rats in New Zealand

Top *Rattus exulans* (Peale) kiore

Middle *Rattus rattus rattus* (Linnaeus) Ship rat

Bottom *Rattus norvegicus* (Berkenhout) Norway rat



the distribution of the ship rat (Southern 1964). In New Zealand Norway rats were widespread in the North and South Islands during most of last century, although their distribution is now restricted and to a large extent they are commensal with man, being generally confined to farms, buildings, towns and streambanks and waterways. They are also present on many offshore islands (Atkinson 1978, 1986, WRLG Research Review 4, 1984).

The Norway rat is the largest and heaviest of the three species, weighting up to 450g in New Zealand. Colouration is similar to kiore with brown fur dorsally and creamy-grey ventrally. Norway rat ears are small compared with kiore and ship rat, and the dorsal surface of a Norway rats hind foot is always completely pale (Cunningham and Moors 1983). Their thick tail is pale ventrally and always clearly shorter than their head and body length. They are basically ground dwelling with only limited climbing ability and nest in the ground in elaborate burrow systems. Norway rats, often referred to as water rats, are excellent swimmers and they are known to forage under water.

Ship rats were the last rat to establish themselves in New Zealand. Although most likely to have arrived on ships in the early half of the 19th century or even late 18th century (Atkinson 1973) it is now generally accepted they did not become widespread until after 1860 in the North Island and after 1880 in the South Island (Atkinson 1973). Today they are common throughout the North and South islands, and Stewart island and have reached many offshore islands (Atkinson 1978, 1986, WRLG Research Review 4, 1984).

The ship rat is the middle sized rat, reaching weights of 225g in New Zealand (Cunningham and Moors 1983). Three colour morphs of *R. rattus* occur in New Zealand:

(1) 'rattus' has uniformly black fur dorsally, sometimes having a blueish look, and uniformly grey belly fur.

(2) 'alexandrinus' is brown dorsally with long black guard hairs and has uniformly grey belly fur.

(3) 'frugivorus' is brown dorsally with long black guard hairs and white or creamy white belly fur.

Reference to these colour morphs suggests all three occur in the South Island but in the North Island only rattus and frugivorus have been found (Best 1968, Daniel 1972, Innes 1977) and only alexandrinus and frugivorus occur on Stewart Island (Gales 1982, this study). The genetics of the colour morphs have been examined by Tomich and Kami (1966) and all three morphs are covered by the trinomial *Rattus rattus rattus*. Other features include large ears, dorsal surface of hind feet uniformly coloured, usually dark, and a tail longer than the head and body length (Cunningham and Moors 1983). Ship rats are generally arboreal and are agile climbers, although they may be ground dwelling or feeding (Daniel 1972). They nest in trees and rarely burrow. Like kiore, ship rats can swim, although they are not known to forage in or under the water.

There can be little doubt that each rat species has had a marked effect on New Zealand native flora and fauna. Their greatest impact would presumably have been immediately after becoming established but those periods are lacking in detailed ecological documentation. Hence much of the evidence supporting the effects of rats on the New Zealand biota is circumstantial (Beveridge 1964, Bettesworth 1972a, Crook 1973, Daniel 1973, Whitaker 1973, 1978, Atkinson 1973, 1978, 1986, Bell 1978, Campbell 1978, Flack and Lloyd 1978, Imber 1978, Ramsay 1978, Moors 1983, McCallum 1986). All three species have been implicated in the reduction of numbers, and in some cases extinction, of species in the New Zealand indigenous fauna. Atkinson (1978) reviews evidence for the effects of rats on the New Zealand vertebrate fauna. He lists known cases of bird predation and summarizes the main impact each rat has on indigenous birds by classifying the types of bird species most frequently preyed on by each rat. Thus Norway rats have their greatest effects on seabirds and ground nesting terrestrial birds, ship rats on perching birds especially forest species while kiore is somewhat intermediate most frequently preying upon both seabirds and forest birds, although affecting fewer species than the other two. Bell (1978) documents the rat irruption on the Big South Cape Islands where ship rat predation was the probable cause of extinction of three bird species and the drastic reduction of several other bird species. They were also held responsible for the reduction of invertebrate numbers, destruction of plants and the elimination of the greater short-tailed bat (*Mystacina tuberculata robusta*) (Daniel and Williams 1984) from these islands. Crook (1973), Whitaker (1973, 1978) and McCallum (1986) suggest kiore predation has caused the reduction of tuatara and lizard numbers and is responsible for the present day disjunct distribution of these groups. Ramsay (1978) reviews the effects of rodents on the New Zealand invertebrate fauna implicating rat predation as a cause of the disjunct distributions of many native invertebrates. Beveridge (1964) has shown that ship rats are a major destroyer of seeds in native forests, although the likely effects on the plant species involved are not known. Campbell (1978) also implicates kiore as a seed destroyer, summarizes known plant foods of all three species and discusses the likely effects rodents have on New Zealand's native vegetation.

Although rats have often been implicated, through predation and competition, as the major causal agents in the reduction in species numbers of both native plants and small animals, alternative views especially concerning the effects of kiore have been postulated. Craig (1986) suggests that predation and competition by kiore may have been too readily cited as the major, if not sole cause of reduction in abundance and numbers of species of many invertebrates, lizards, tuatara, and birds on northern offshore islands. He proposes that habitat degradation may be of greater significance.

Diet studies also indicate what species are affected by rats, although the degree of effect requires detailed knowledge of the prey species. Studies of ship rat diet in New Zealand include Best (1968), Daniel (1973), Innes (1977), Clout (1980) and Gales

(1982). Generally all studies show invertebrates, especially wetas, and berries and seeds are the main diet items. In all cases a seasonal shift in diet is noted with invertebrates most important in summer and berries and seeds the most important in winter. Birds were found not to be an important diet item, although predation probably did occur. Norway rat diet studies in New Zealand include Beveridge and Daniel (1965), Bettesworth (1972a), Bettesworth and Anderson (1972), Moors (1985) and Dick (1985). In general, invertebrates, seeds and fruits predominate but birds are extremely important in certain populations (Bettesworth 1972a). Lizard remains have been found in Norway rat stomachs and fresh water mussels (*Hyridella*) and crayfish (*Paranephrops*) have been cited as food items by Buller (1870), Johnstone (1870) and Beveridge and Daniel (1965). New Zealand studies of kiore diet (Bettesworth 1972b, Hicks *et al.* 1975, Campbell *et al.* 1984, Dick 1985) indicate a predominance of plant foods, especially seeds, and of invertebrates, although Hicks *et al.* (1975) found large amounts of bird down in the stomachs of kiore on Koropuki Island, (Mercury Islands).

Comparisons between studies from offshore islands and the New Zealand mainland show that generally much greater densities of rats are found on islands (Daniel 1978). This may be attributable to the absence of important mainland predators or as there are often fewer species on islands (MacArthur and Wilson 1967) those present may be subject to less competition and therefore have greater access to available resources. Most studies on ship rats in New Zealand were in mainland forests whilst all Norway rat and kiore studies were on islands. For kiore this reflects their distribution as the only mainland populations are in a few areas of Fiordland. Low population densities of ship rats have been found in the Orongorongo Valley (Daniel 1972, 1973, Fitzgerald and Karl 1979), Tiritea Reserve (Innes 1977), although high capture rates were reported by Beveridge (1964) in a North Island podocarp forest, Best (1968) in two South Island forests and by Clout (1980) in a pine forest in the North Island. High populations of Norway rats were found by Beveridge and Daniel (1965) on Mokoia Island and Bettesworth (1972a) on Whale Island. Moors (1985) found densities of between 2.5 - 4.2 rats/ha on islands in the Noises group. Dick (1985) found a high abundance of kiore and Norway rats on Kapiti island supporting a previous finding of high numbers of Norway rats on Kapiti (Daniel 1969).

1.2 Rats on Stewart Island

Coexistence of the rat species in New Zealand is the subject of much conjecture and is little understood. Various combinations of the four rodent species exist in New Zealand. As indicated earlier all three rat species occur on Stewart Island, but mice and mustelids do not. To date, this species assemblage is not known in any other habitat in New Zealand. Hence Stewart Island is important to consideration of theories on competition and coexistence of rodent species in New Zealand. Initially kiore were thought to be restricted by Norway rat predation (Meeson 1884, White 1897, Watson 1956, Williams 1973), although Atkinson (1973) showed that the disappearance of kiore in the North and South Islands coincided with the spread of ship rats. He suggested either predation or competition from ship rats was a more likely cause of the decline in kiore numbers. With the knowledge that kiore existed on Stewart Island with both the other species of rat yet in the absence of mice, Taylor (1975) suggested that competition from mice was the major factor contributing to the decline of kiore and that in New Zealand a niche no longer exists for kiore once ship rats, Norway rats and mice have all become established. The cause of Norway rat decline and their subsequent restricted distribution was attributed to competition from ship rats (Atkinson 1973). Taylor (1978), however, believes differential predation by stoats to be more important implying that such predation restricts the distribution of Norway rats allowing ship rats to become widespread. The coexistence of Norway and ship rats on Stewart Island in the absence of stoats, and the high forest populations of Norway rats on certain offshore islands, for example Kapiti and Raoul, again in the absence of stoats lends support to Taylor's belief. Therefore, in summary of the Stewart Island situation Taylor (1978) suggests it may be that in the absence of stoats, Norway rats thrive which in turn may prevent mice from becoming established which would otherwise exclude kiore.

1.3 Aims

(1) To investigate the abundance of the three *Rattus* species and to examine the effects of seasonal and habitat variations on that abundance.

(2) To provide morphological and reproductive data on Stewart Island rats.

(3) To examine the diet of each species and if possible to relate dietary difference to their coexistence.

(4) To examine the availability of food in each habitat and to consider how this may effect the diet of each species.

1.4 Study Area

1.4.1 Stewart Island

General Description

Stewart Island, lying between 46^{o} 40' and 47^{o} 18' South and between 167^{o} 19' and 168^{o} 17' East (NZMS 219 Stewart Island), is the most southerly of the three main islands of New Zealand. It is separated from the South Island by Fouveaux Strait which has a minimum width of 21km. The Island is irregularly triangular in shape with a total area of approximately 172000ha. At its longest the island stretches northeast to southwest for approximately 65km and is approximately 40km wide.

The coastline is rough and rocky with only a few sandy beaches in the northeast and at Mason Bay on the west coast. The major inlet is Paterson Inlet which extends 15km westward almost bisecting the island. To the southeast Port Pegasus extends northeast to southwest for 11km with an average depth of 20 fathoms.

The interior of the island is everywhere hilly with the exception of small areas at Mason Bay, the valley of the Freshwater River and at the head of Halfmoon Bay and Paterson Inlet. In the north-west part of the island ridges run west to the highest peak on the island, Mt Anglem at 980m. Running south-west from Paterson Inlet mountains rise culminating in the Tin Range and massive granite cones above Port Pegasus.

The Stewart Island county which includes the island of Raupuke and its outlying islands, has an area of 1746 km^2 and a permanent population of approximately 400 (1980). Transport to the island is by regular flights from Invercargill and a ferry which leaves from Bluff.

Vegetation

The island is predominantly covered with forest and scrub except for alpine tops and small areas of flat river valley on the Freshwater, Rakeahua and Toitoi rivers and parts of Mason Bay flats. The composition of vegetation varies with altitude. 'Mutton bird scrub' principally puheretaiko (*Senecio reinoldii*), tete-a-weka (*Olearia oporina*), and leatherwood (*Olearia colensoi*) grows along the coast. Forest rises from this scrub or directly from the shoreline to approximately 300m, giving way to manuka (*Leptospermum scoparium*) and/or yellow silver-pine (*Lepidothamnus intermedius*) scrub. The principal forest trees are rimu (*Dacrydium cupressinum*), kamahi (*Weinmannia racemosa*), miro (*Prumnopitys ferruginea*), thin barked totara (*Podocarpus hallii*) and southern rata (*Metrosideros umbellata*). In the south where it is boggy or on open ridges these species may be replaced by yellow silver-pine accompanied by extensive carpets of mosses and liverworts. Above approximately 450m manuka scrub gives way to *Olearia* scrub. Vegetation on windswept, alpine tops mainly comprises mosses, club moss (*Lycopodium ramulosum*), comb sedge (*Oreobolus pectinatus*), tussocks (*Chionochloa* spp.), mountain daisy (*Celmisia polyvena*), *Brachyglottis bellidioides*, and other herbs (Best 1984).

Geology

Stewart Island is a granite mass forced through an overlying surface material composed of biotite-schist and diorite which has subsequently all but been removed by weathering.

Cultural Influences

Little is known of pre-European occupation of Stewart Island. Excavations have shown that parts of the Island were occupied by a moa hunting, Polynesian people as early as the 13th century, before the Great Fleet of the Maori reached New Zealand (Sansom 1982). To the Maori, Stewart Island was generally a place of peace and tranquility which is reflected in the name they gave the island - Rakiura 'Island of the glowing sky.'

European contact with Stewart Island began in 1770 when Captain James Cook sailed around the southern coast. Sealing, whaling, gold and tin mining, farming and ship building were all attempted on Stewart Island, with varying degrees of success. Sealing stations and whaling bases were established along the coast in the early 1800s. Felling of timber generally occurred wherever settlements were established and the tin mining operations on the Tin Range led to the building of a jetty and three miles of tramway from Port Pegasus up to the heart of the Tin Range

Fishing has been the economic mainstay of Stewart Island and today chiefly involves crayfish boats working along the coast.

Tourism causes the greatest impact on Stewart Island at present and much of the island exists as either scenic or nature reserves.

1.4.2 Robertson River Region

The Robertson River Region (grid reference 21136 53275) is an area of approximately 8 km^2 within the Department of Conservation's Kakapo Study area[2] in southern Stewart Island (figure 1, p. 9). It is situated north-east of Port Pegasus and extends from the foot of the Tin Range to the mouth of the Robertson River on the southern coast. The region is part of a nature reserve administered by the Department of Conservation.

A hut at Scollay's Flat, which lies in the upper reaches of the Robertson River catchment, provided a base camp for the rat trapping programme. Observations in 1986 revealed a mean winter temperature of about 5°C (range -3.5 - 14°C) and a mean summer temperature of about 12°C (range 4 - 22°C). Complete records of rainfall for Scollay's Flat are not available, although for Oban, 40km to the northeast, rainfall was spread fairly evenly throughout the year averaging 1467mm per annum (1914-1975; N.Z. Meteorological Service 1983).

Description of Habitats Trapped

The Robertson River Region (figure 2, p. 10) comprises a complex mosaic of vegetation types which have resulted partly from former tin mining excavations and burning of vegetation, partly from variable topography and soil types and partly from local influences of aspect, exposure, altitude, and drainage.

---

[2] Prior to April 1 1987, this area was administered by the New Zealand Department of Lands and Survey.

FIGURE 1: Stewart Island and location of study area

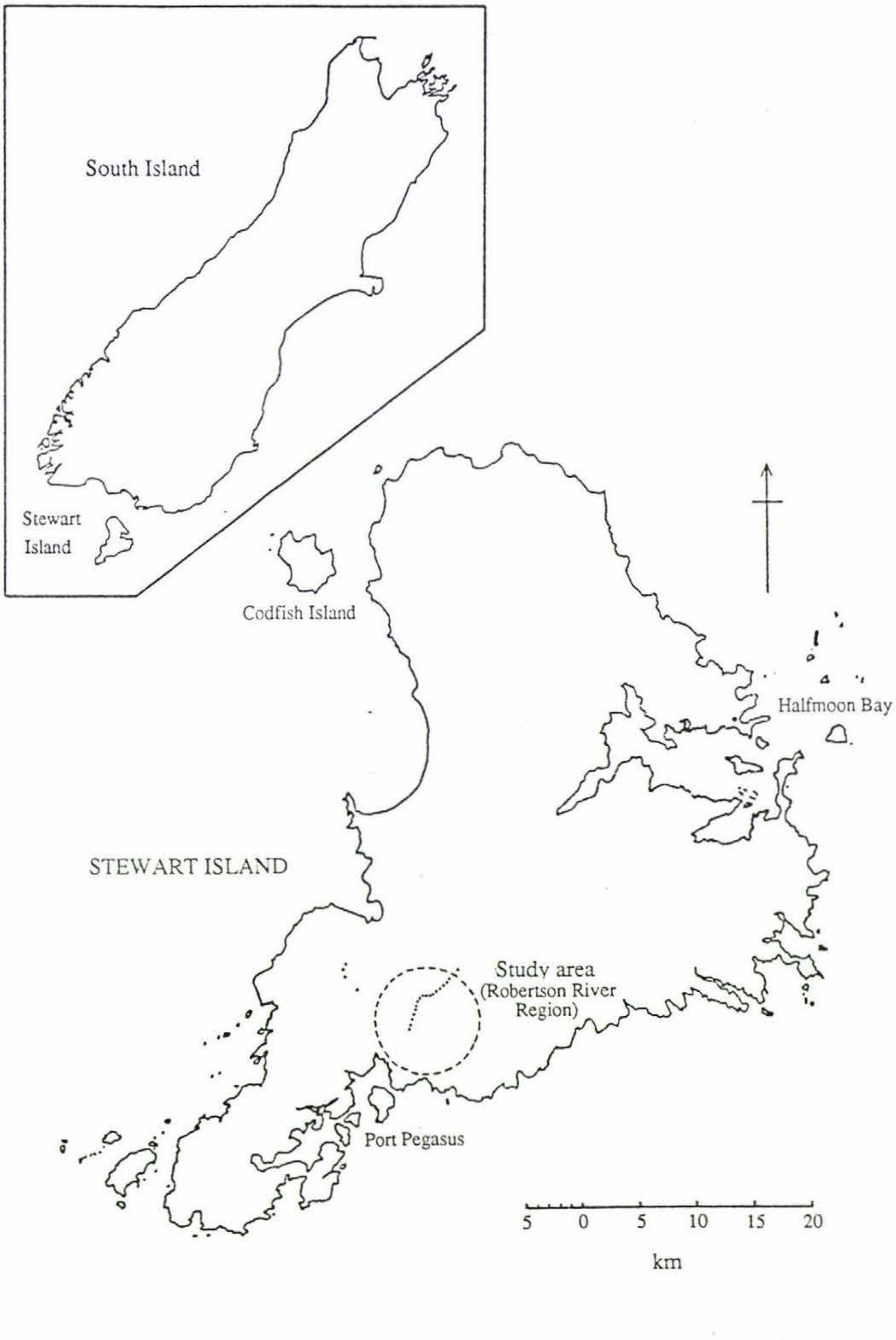
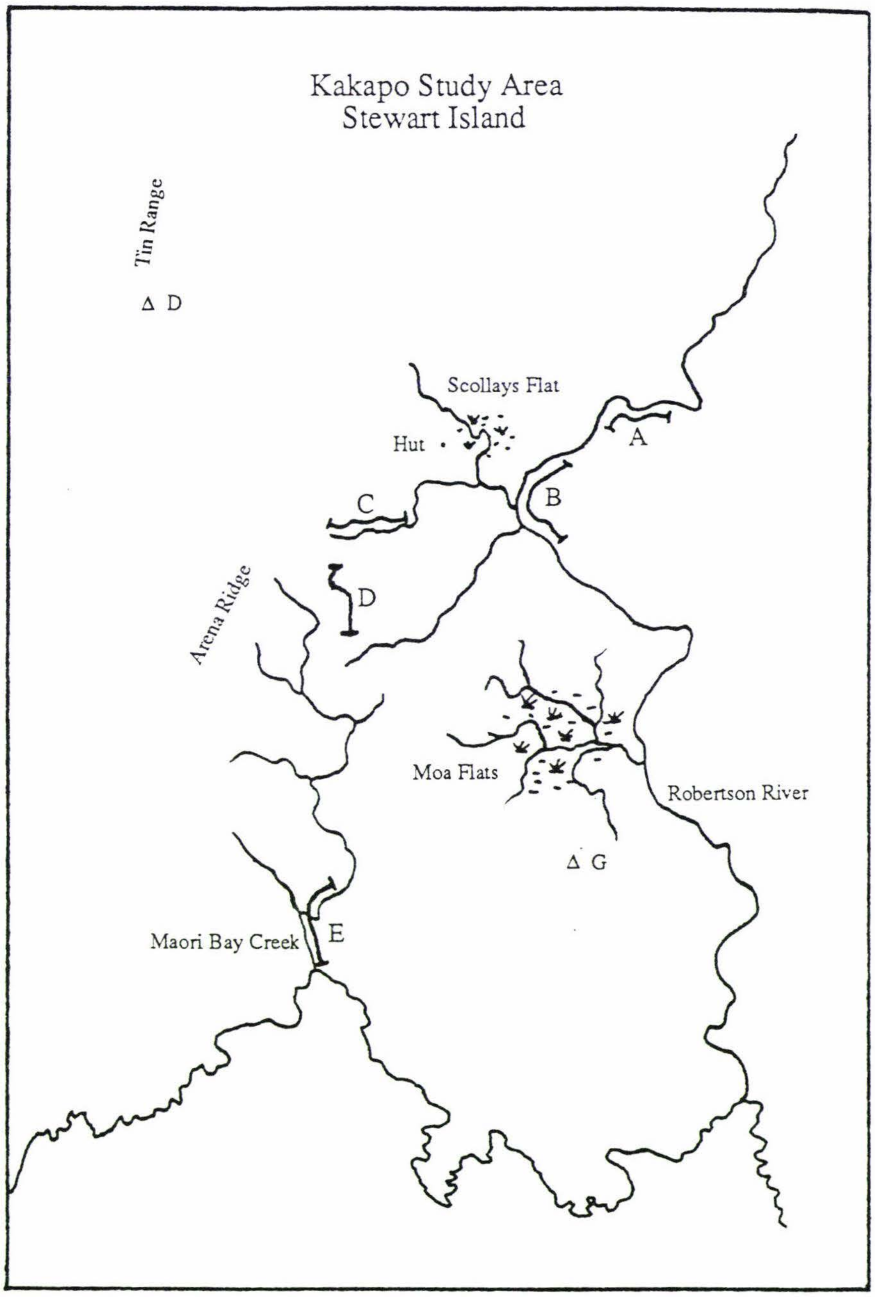


FIGURE 2: Robertson River Region of Kakapo Study area and location of trapping lines



Δ = Trig pionts ⊢⊣ = Trapping lines

Initially, New Zealand Wildlife Service staff[3] trapped five transects in five different habitats (figure 2, p 10). These were deemed to be representative, first, of the whole area, and second, of habitat used by kakapo (P. Moors pers comm).

The transects were in the following habitats :

Transect A

Poorly drained flats covered with umbrella fern (*Gliechenia circinnata*), *Scirpus*, and scattered thickets of manuka.

Transect B (plate 2, p. 12)

Inland podocarp-kamahi forest on river flats and in damp sheltered gullies. Major forest trees were kamahi, southern rata, miro, rimu and occasionally thin barked totara. Understorey species principally comprised broadleaf (*Griselinia littoralis*), Coprosma species (especially *C foetidissima*, *C colensoi* and *C lucida*), pepperwood (*Pseudowintera colorata*), rohutu (*Neomyrtus pedunculata*), prickly mingimingi (*Cyathodes juniperina*) and occasionally *Pseudopanax simplex*. Common forest floor plants included *Gahnia procera*, bush rice grass (*Ehrharta diplax*) and *Blechnum* ferns (especially *B discolor*).

Transect C (plate 3, p. 12)

Yellow silver-pine-podocarp forest on wet south-facing slopes. Principal forest trees comprised yellow silver-pine, southern rata, and occasionally miro, rimu and pink pine (*Halocarpus biformis*). Understorey species included prickly mingimingi, inaka (*Dracophyllum longifolium*), manuka, weeping mapou (*Myrsine divaricata*) and *Coprosma colensoi*. The forest floor was extensively covered with carpets of mosses and liverworts and other common species included lanternberry (*Luzuriaga parviflora*), *Blechnum* ferns and *Gahnia procera*.

Transect D (plate 4, p. 14)

Dense yellow silver-pine scrub on well drained ridges. Yellow silver-pine generally not exceeding about two metres in height, dominated this transect with scatterings of manuka and prickly mingimingi. Stunted rimu, southern rata and pink pine also occurred. Ground cover species principally comprised dwarf heaths (*Cyathodes empetrifolia* and *Pentachondra pumila*) and club mosses (especially *Lycopodium ramulosum*). *Gahnia procera* was also common.

---

[3] The New Zealand Wildlife Service was incorporated into the Department of Conservation April 1, 1987.

PLATE 2: Vegetation on Transect B

PLATE 3: Vegetation on Transect C

Transect E (plate 5, p. 14)

Coastal podocarp-kamahi forest. Principal forest species included kamahi, miro, southern rata, and totara. Understorey species included broadleaf, tree ferns (*Cyathea/Dicksonia squarrosa*), *Coprosma* species (especially *C foetidissima*), inaka and occasionally yellow silver-pine, prickly mingimingi, pepperwood and *Pseudopanax simplex*. Major forest floor species include *Blechnum* ferns, *Gahnia Procera, Netera* sp. and many liverworts and mosses.

Transects A and B were on the eastern banks of the upper reaches of the Robertson River near Scollay's Flat. Transects C and D were situated on the plateau region of the Maori Bay track north-west of Moa Flat. Transect E was at the seaward end of the Maori Bay track and ended where forest met beach at the mouth of the Maori Creek. (figure 2, p.11)

PLATE 4: Vegetation on Transect D

PLATE 5: Vegetation on Transect E

2
Methods

2.1 Trapping

Wildlife Service staff carried out rat trapping in the Robertson River region of Stewart Island between June 1982 and December 1985. The study, headed by P.J. Moors and D.M. Cunningham, was primarily to obtain an index of abundance of the species present in this area. Stomachs of all rats captured were collected and made available to me for examination. From March 1986 to December 1986 I pursued my own trapping programme over the same trapping lines. The contents of all stomachs from both trapping programmes were examined.

Rat trapping was conducted along transects within the five different habitats described in section 1.4.2 (p. 8). Each transect consisted of a line of snap-traps set for three nights every three months. Trips to Stewart Island, of two weeks duration, were undertaken in March, June, September, and December of each year and these months will be referred to as autumn, winter, spring and summer respectively. Permanent trap-sites were installed along each transect approximately thirty metres apart and two Australian "Eazi-set", snap-traps set at each site. One trap was baited with a mixture of peanut butter and oats, the other with a salami and cheese mixture. The traps were set under plastic covers with wire hoops at the entrances to minimize interference from possums (*Trichosurus vulpecula*) and to prevent accidental capture of birds.

Prebaiting was initially attempted by Wildlife Service staff. This entailed baiting the traps and leaving them unset for one night. Prebaiting began in December 1982 but after no significant increase in trapping success by June 1983, the practice was discontinued (P. Moors pers comm.). I did not attempt prebaiting as it was appropriate for me to follow the previous trapping regime and in any case time constraints mitigated against the practice.

Initially transects A and C contained 18 trap-sites, transects B and E 20, and transect D 19. In December 1982 transect A was extended to 23 trap-sites, transect B to 25, transect C to 22, transect D to 24, and transect E to 25. Later in December 1983 transect B was increased to 30 trap-sites, transect D to 29 and transect E to 28, and in March 1984 transect B was finally reduced back to 25 trap-sites. These changes were deemed necessary because low capture rate and small sample-size raised doubts about the reliability of the data. In an attempt to overcome this problem the number of sites on each transect was increased (D.Cunningham pers comm.). Transect A was discontinued after June 1983 for these reasons. In addition, kakapo were found not to use this habitat and moreover there was insufficient time to deal with all five transects during the two-week period of a trip. This meant that one transect had to be abandoned and transect A was the logical one (P. Moors pers comm.). For this reason results of trapping and stomach analysis for rats caught on transect A are not recorded in this thesis. All further mention of the four transects trapped refers to transects B, C, D, and E. The number of rats caught and indices of abundance for transect A are, however, included in Appendix 1. During my trapping programme (March 1986 to December 1986) the number of trap-sites remained unchanged from the final number on each transect mentioned above.

Transects were checked and if necessary cleared and reset each morning of the three night period. Details of each trap were recorded following Cunningham and Moors (1983). All captured rats were taken back to the hut and autopsied.

Indices of abundance were calculated following Nelson and Clark (1973) and Cunningham and Moors (1983). They are expressed as number of captures/100 trap-nights.

$$I.A = \frac{C \times 100}{CTN}$$

where I.A = index of abundance, C = captures and CTN = corrected trap-nights. Corrected trap-nights are calculated making allowance for traps which have been set off, whether they have caught a rat or not.

The total number of trap-nights = number of traps x the number of nights they are set

and

Trap nights lost = total traps sprung by all causes

(assuming that on average traps were sprung for half the night (Nelson and Clark 1973)).

Therefore

Corrected trap-nights (CTN) = Total trap-nights - trap-nights lost

The distance each trap-site was from running or standing water was recorded by D. Cunningham (pers comm.). Distances were divided into five categories:

(1) 0 - 5m
(2) 5 - 10m
(3) 10 - 15m
(4) 15 - 20m
(5) > 20m

The relationship between captures and the distance from water was investigated for each species. The percentage of captures in each distance category was divided by the percentage of trap-sites in that category in an attempt to allow for the differing availability of trap-sites in each distance category.

$$\frac{\text{Percentage of captures in distance category X}}{\text{Percentage of traps in distance category X}} = \text{W.I}$$

Therefore if trap-sites were capturing rats in proportion to the number of trap-sites in each distance category a water index (W.I) of 1.0 or very close to it should be obtained. If a W.I was greater than 1.0 for a particular distance category then captures were greater than would be expected if they were proportional to the number of trap-sites. Therefore a distance category with W.I larger than 1.0 should indicate that the rats have a positive affinity (preference) for this distance from water and a category with W.I less than 1.0 should indicate the rats have a negative affinity for the distance from water.

2.2 Autopsies, Morphometrics and Reproduction

Autopsies were carried out in the Scollay's Flat hut. Date, trap line, trap number, species, and sex of each rat were recorded. Body measurements and reproductive condition were also recorded. Head and body length was measured from nose tip to the position where a fine pointer, slid along the tail is stopped by the pelvis (Cunningham and Moors 1983). Weight was recorded, to the nearest 5g, using a spring balance.

Rats were considered sexually mature if males had scrotal testes and if females had perforate vaginas. The presence of macroscopically visible epididimal tubules was also recorded, although inconsistencies in these recordings mitigated against their use in the analyses. Any scars and deformities were noted. Stomachs were removed and stored in 70% alcohol for later examination of contents at Massey University. Skulls not smashed by the trap were removed and stored in 70% alcohol for later aging by molar wear. They have been retained, although time did not permit their examination in this study. Ectoparasites were also stored in 70% alcohol for later identification.

2.3 Stomach Analysis and Diet

Stomach analysis generally followed the methods of Dick 1985. Initially, stomach contents were washed through a three tier sieve system of decreasing mesh size from 2mm to 1mm to 0.25mm. Each sieve fraction was put in a petri dish, its proportion of the total contents estimated, and examined under a dissecting microscope.

Diet items were sorted into six major food categories, invertebrate, vertebrate, vegetation, wood, fungus, and other. These categories were selected after canvassing previous rat studies (Best 1968, 1969, Bettesworth 1972a, 1972b, Daniel 1973, Williams 1973, Innes 1977, Clark 1980, Clout 1980, Gales 1982, Dick 1985, Moors 1985). Two methods were used to quantify the information gained from stomach analysis. The percentage frequency of occurrence of the food categories was calculated. This is the number of stomachs in which a category occurred expressed as a percentage of the total number of stomachs examined. The second method involved the visual estimation of the percentage volume of each food category in the stomachs. Percentages for each food type per fraction were combined giving a total percentage for each stomach. Invertebrates and vegetation were stored for later, more detailed identification.

2.3.1 Invertebrates

Invertebrate remains occurred mostly as fragments. They were impossible to identify to species level and were sorted only as far as time and expertise allowed. I collected invertebrates from the study area (see section 2.5, p. 20) and attempted to match fragments from stomachs with these. Rogan Colbourne (Department of Conservation) assisted in identifying many of the fragments as far as possible. The frequency of occurrence of all invertebrates was recorded.

2.3.2 Cuticle Analysis

Cuticle analysis was carried out on plant material from the stomachs generally following the methods of Fitzgerald A. (1976) and of A. Grant (pers comm.). The plant material was macerated in household bleach (active ingredient sodium hypochlorite) until the mesophyll dissolved. The remaining cuticle was then filtered through Whatmans 91 filter paper and washed several times with water to remove the bleach. After all traces of bleach had been removed, the material was stained with basic fuchsin and stored in glycerol. A semi-permanent slide was prepared by placing a drop of the glycerol and plant material on a slide and covering it with a 22 x 60mm cover slip. The cover slip was then sealed using nail polish.

A reference collection of cuticles from plants in the area was prepared in the same way, although the plants were first blended in an ordinary kitchen blender to reduce the particles to sizes similar to those found in the rats' stomachs. I also had access to A.D. Grant's established reference collection of plant cuticles from the study area.

The plant material was identified to species level using a compound microscope at 100x or 400x magnification. Plants were recorded on a presence/absence basis. Initial attempts to quantify the plant foods following A. Grant (pers comm.) proved far too time consuming and were discontinued.

2.3.3 Cuticle Analysis Additions

To identify plant cuticles that may be present in rat stomachs via gut contents of ingested invertebrates, cuticle analysis was performed on several wetas and one stick insect. The size, i.e. maximum length, of cuticles from the weta guts was recorded.

In addition a simple, but subjective, quantification of plant cuticles in rat stomachs was attempted by recording whether each item identified in a sample was abundant or merely present. If a cuticle occurred only once or twice in a sample then it was recorded as being present, if it occurred more than twice it was recorded as abundant.

The size (maximum length) of cuticles was noted with particular reference to being weta size or not, i.e. if a plant item only occurred in a stomach sample with cuticles of a size smaller than or equal to the maximum cuticle size found in weta guts it was recorded as weta size.

2.3.4 Vertebrates

Bones, feathers, and skin were removed and identified as mammal, lizard or bird.

2.4 Statistical Analysis

Standard statistical procedures were used to analyse the results. Three-way analysis of variance using the SPSSX MANOVA procedure was used to test for differences in index of abundance and weights between species, seasons and transects. Examination of parameter estimates was used to assess the pattern of response to each variable, eg. the ranking of abundance indices for the four seasons. Multiple comparisons of means using the Scheffe method were also performed following one-way analyses of variance.

Cochran's univariate homogeneity of variance test and normal plots of cell frequencies (SPSSX) indicated that a log transformation of the index of abundance data was appropriate.

Chi-square tests (Sokhal and Rohlf 1969) were used to test whether the sex ratio of each species differed significantly from unity.

Multivariate analysys of variance and discriminant function analysis, again using the SPSSX MANOVA procedure, and Chi-square homogeneity tests (Dixon and Massey 1969) were used to describe the diets of the three rat species. Multivariate analysis of variance was used to test differences in the volumes of diet categories between species, transects and seasons. The chi-square test of homogeneity was used to test for differences in the frequency of occurrence diet data and discriminant function analysis further enabled separation of the three species diet and identification of diet items most valuable in describing each species' diet.

2.5 Food Availability

In addition to the rat trapping, studies on the invertebrate fauna and phenology of plants in the study area were conducted during the trapping periods to assess possible changes in the availability of likely rat foods.

2.5.1 Invertebrate Sampling

Two types of invertebrate sampling were conducted during each two week trip, pitfall trapping and night sampling.

Pitfall Trapping

A line of pitfall traps was set for five nights along each transect every three months from March 1986. Plastic containers 12cm diameter by 12cm deep were embedded in pits, their tops level with the ground. So that invertebrates falling into the traps were killed and preserved, 2 to 3cm of 10% formalin was placed in the bottom of each trap. It was impossible to prevent surface water entering the traps but plastic covers 20cm x 20cm placed over them prevented exposure to falling rain. Frequent checks prevented surface water that entered the traps from being a serious problem.

Invertebrates from all pitfall traps along each line were pooled giving a single invertebrate sample of each line for each trip. Thus simple comparisons between transects and between trips could be made.

Night Sampling

Night sampling involved a one hour period of invertebrate collecting on each transect every three months from March 1986 to December 1986. During these periods I searched for and collected all invertebrates encountered by scratching in the leaf litter, searching on the vegetation and hunting on the forest floor. The invertebrates caught were stored and added to the invertebrate collection from the area.

Apparatus used to capture the invertebrates during the night sampling were torch, tweezers, small plastic containers, and an aspirator (figure 3, p. 22).

2.5.2 Phenology

Phenological surveys of the vegetation on each line were started in March 1986. Five individuals of ten different species of plants were tagged and phenological observations were recorded every three months. The species chosen were common and were likely rat foods. The three phenological stages were divided into the following classes:

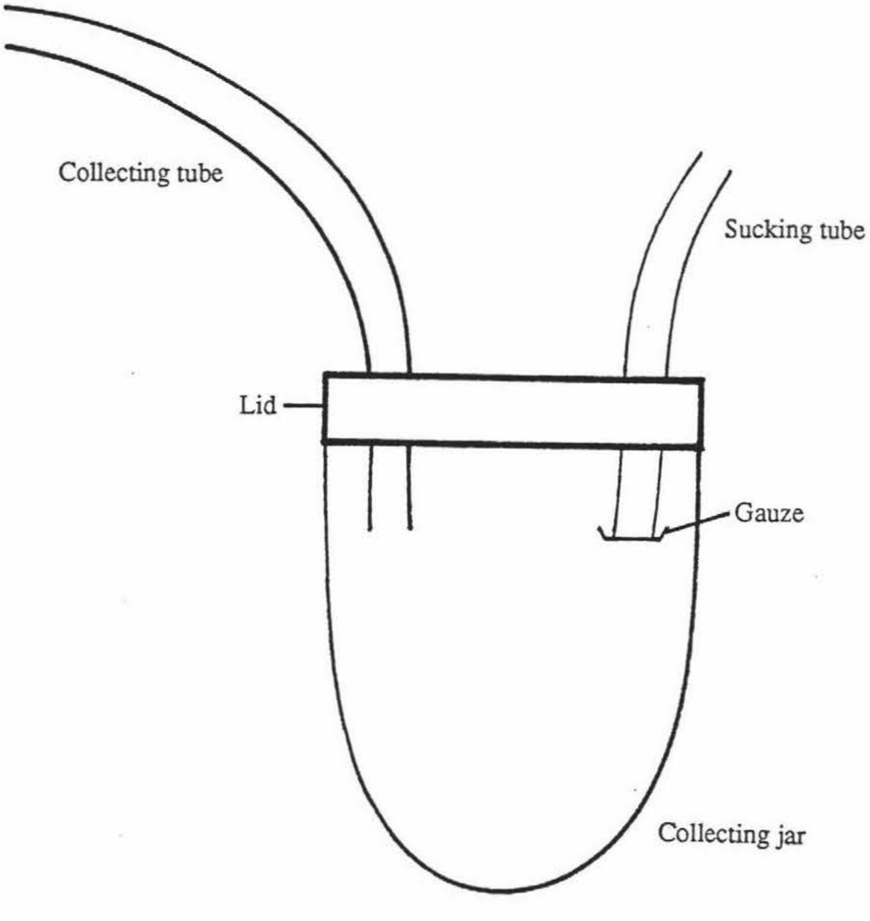
(1) Vegetative Growth ----	Leaf buds Leaf buds expanding New leaves

(2) Flowering ----	Flower buds
	Flower buds expanding
	Flowers
	Petal fall
(3) Fruiting ----	Unripe fruit
	Ripe fruit
	Seed fall

The tagged plants were checked each sampling period and classes scored on a four point scale:

0 = not present
1 = present
2 = abundant
3 = super abundant

FIGURE 3: Aspirator used in night invertebrate sampling



3

Results

3.1 Rat Trapping

A total of 434 rats were trapped between June 1982 and December 1986. Only one rat was unidentifiable due to scavenging and no non target animals were captured although suspected possum interference did occur. Summaries of rat trapping are presented in table 1 (p. 24), table 2 (p. 24) and as Appendix 1 (p. 121).

3.1.1 Index of Abundance

A total of 434 captures from 10833.5 corrected trap-nights (Nelson and Clark 1973) corresponds to an overall index of abundance of 4.0 rats/100 trap-nights. Highly significant differences were found between each species index ($p < .001$). Ship rats had the highest index of 1.8, kiore 1.7 and Norway rats the lowest of 0.6 rats/100 trap-nights. The Scheffe test indicated that Norway rat abundance index was significantly different from both ship rat and kiore but there was no difference between ship rat and kiore indices (Appendix 2, p. 122).

The overall index of abundance differed significantly between seasons ($p < .001$) but not between transects ($p = .489$). Abundance was highest in winter and decreased over spring and summer to reach a low in autumn in each year of trapping (figure 4, p. 25). When species variation was incorporated significant seasonal differences were found ($p = < .001$). The seasonal changes in ship rat and kiore indices were similar with greatest indices recorded in winter, decreasing over spring and reaching lows in summer for ship rats and autumn for kiore (figure 5, p. 26). Norway rats showed little seasonal changes, although small peaks occurred in the winter and summer of 1984 (figure 5).

Highly significant differences were found between the abundance indices of each species in each habitat ($p < .001$), indicating very different species compositions on each transect (figure 6, p. 27). On transect B, ship rats had the highest index whilst that for Norway rats was less than half that of ship rats. A markedly lower index was recorded for kiore (figure 6). High indices were recorded for kiore and ship rats compared with the very low index for Norway rats on transect C. Kiore totally dominated transect D having the highest index for a single species on a transect (figure 6). Very low indices were recorded for ship rats and only one Norway rat was ever caught on this transect. On transect E, ship rats predominated with Norway rat index less than half that for ship rats (figure 6). Kiore index on E was considerably lower still (figure 6). The seasonal species compositions on each transect are presented in figure 7 (p. 28).

TABLE 1: Total Captures

Transect	Ship rat	Kiore	Norway rat	Total
B	55	5	27	87*
C	49	54	7	110
D	15	110	1	126
E	74	10	26	110
Total	193	179	61	433

* = 1 scavenged, unknown species not included.

TABLE 2: Seasonal Captures

Season	Ship rat	Kiore	Norway rat	Total
Autumn	26	19	12	57
Winter	102	81	18	201
Spring	40	35	13	88*
Summer	25	44	18	87
Total	193	179	61	433

* = 1 scavenged, unknown species not included.

FIGURE 4: Seasonal changes in Overall Index of Abundance

A = Autumn
W = Winter
Sp = Spring
Su = Summer

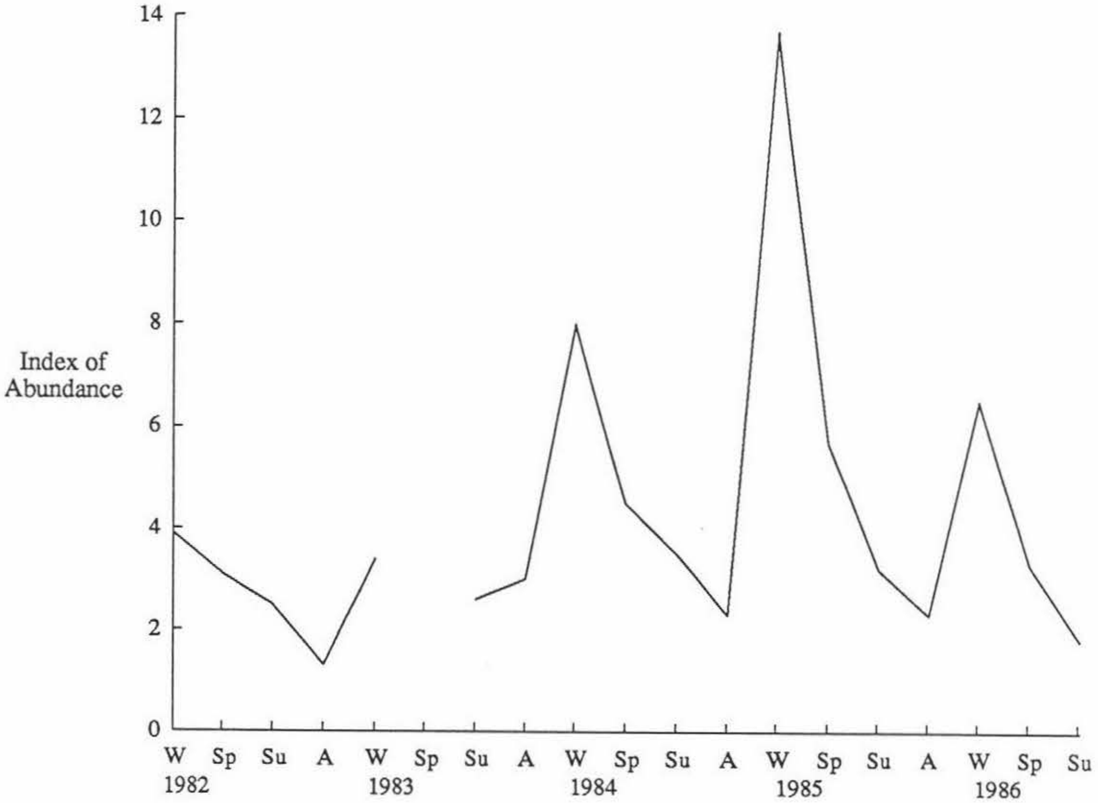

14
12
10
8
6
4
2
0
Index of Abundance
W Sp Su A W Sp Su A W Sp Su A W Sp Su A W Sp Su
1982
1983
1984
1985
1986
Trapping Session

FIGURE 5: Seasonal changes in the Index of Abundance of each Species

— Ship rat

+ Kiore

✳ Norway rat

A = Autumn

W = Winter

Sp = Spring

Su = Summer

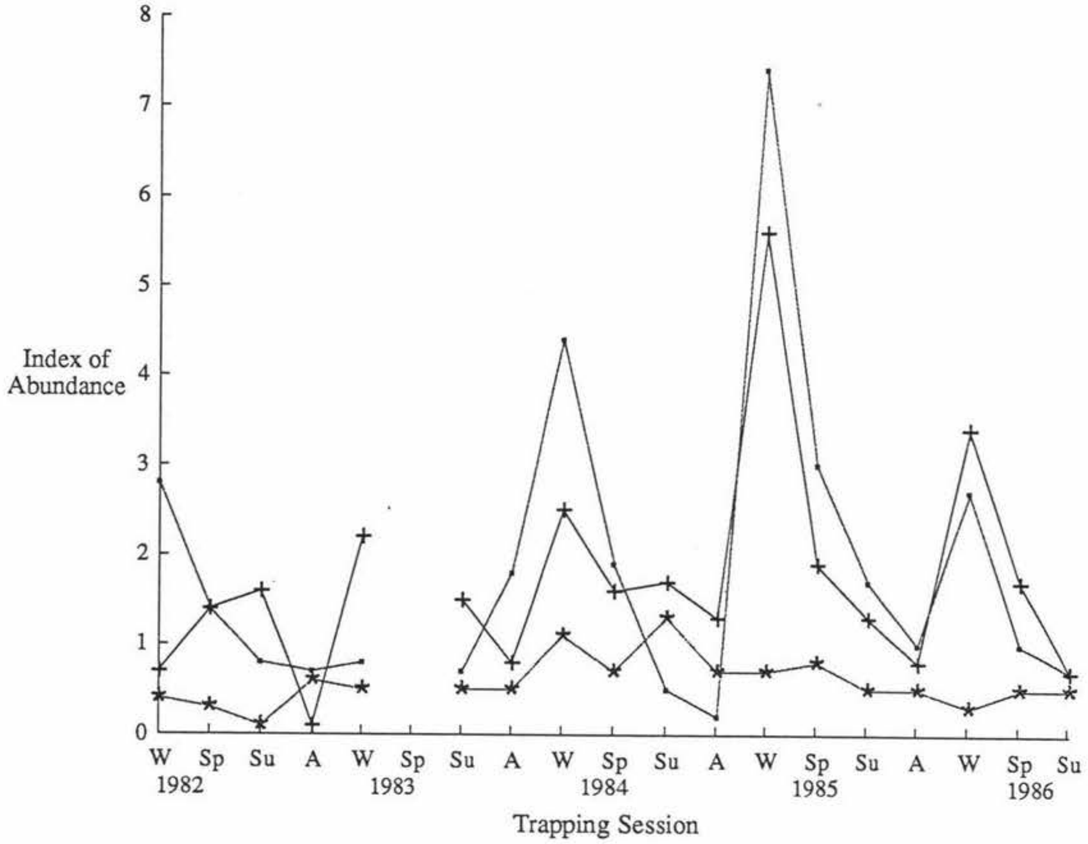

Index of Abundance
0
1
2
3
4
5
6
7
8
W
Sp
Su
A
W
Sp
Su
A
W
Sp
Su
A
W
Sp
Su
A
W
Sp
Su
1982
1983
1984
1985
1986
Trapping Session

FIGURE 6: Index of Abundance of each Species on each Transect

■ Ship rat

▩ Kiore

▨ Norway rat

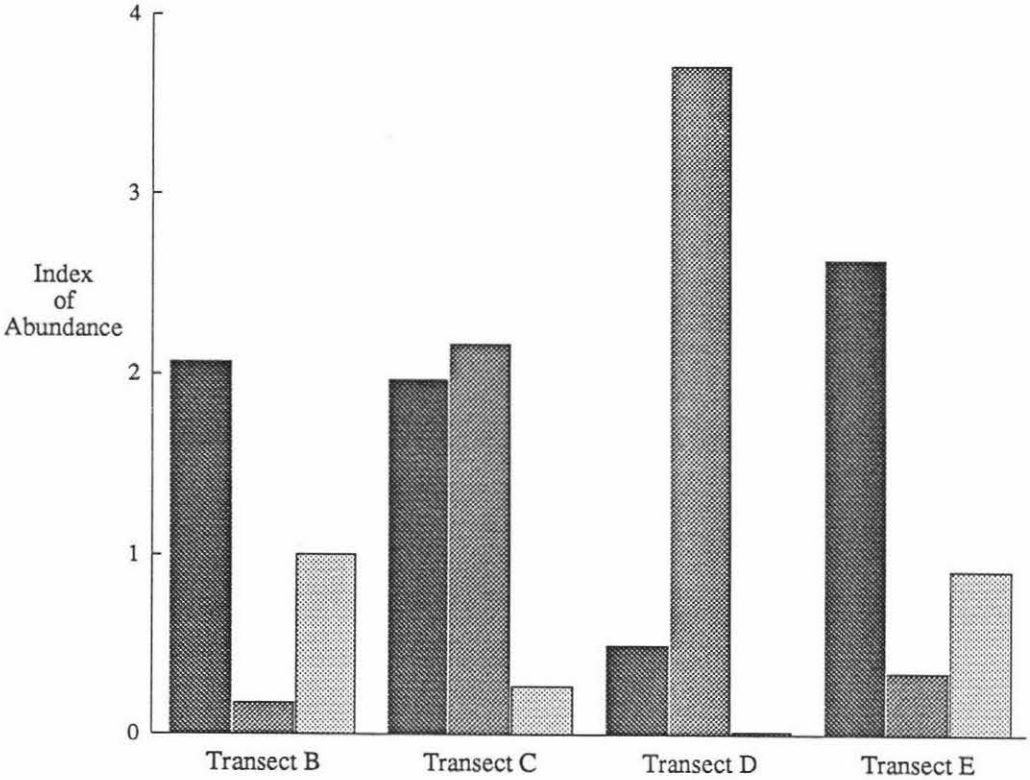
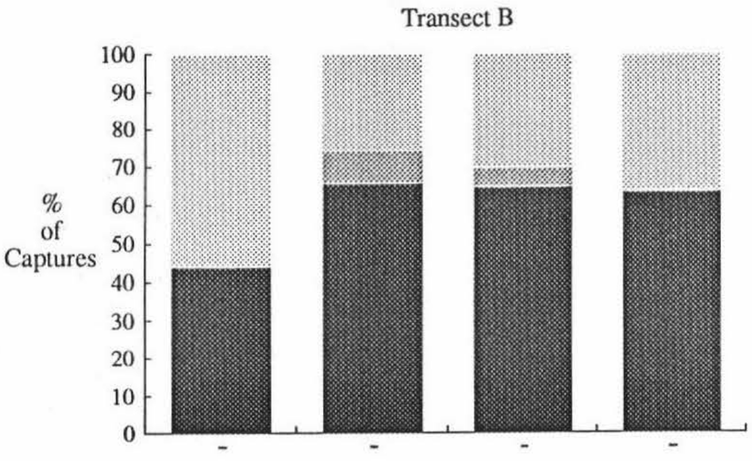

4
3
2
1
0
Index
of
Abundance
Transect B
Transect C
Transect D
Transect E

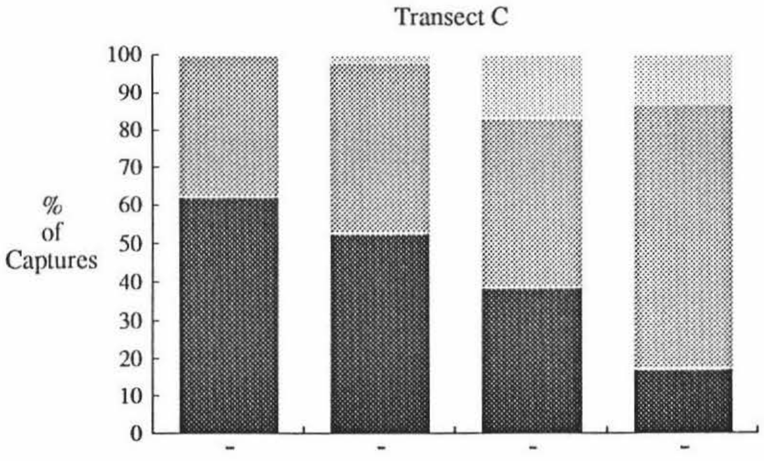
FIGURE 7: Seasonal Species Composition on each Transect

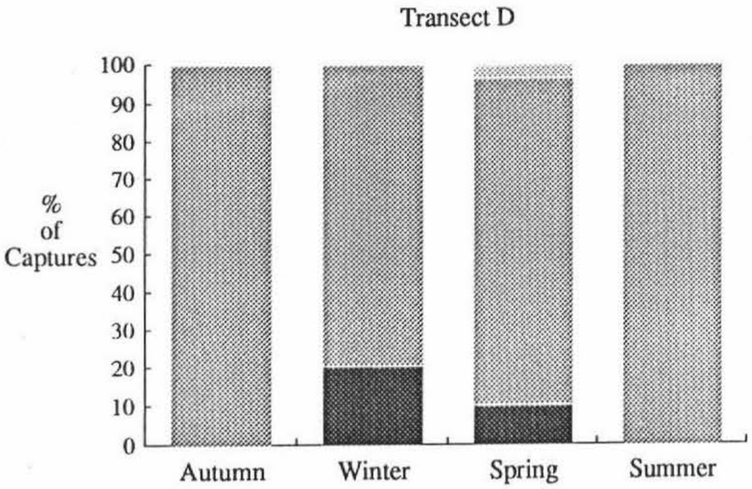
■ Ship rat

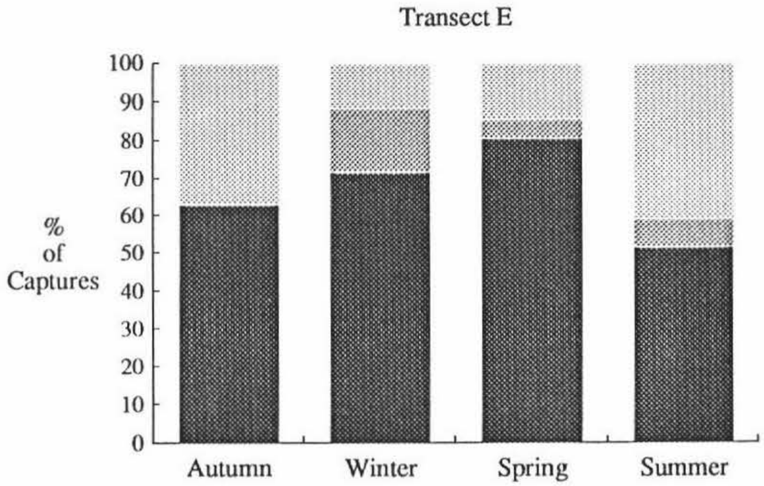
▩ Kiore

▨ Norway rat


Transect B


Transect C


Transect D


Transect E

3.1.2 Relationship between Captures and Distance from Water

The distances between trap-sites and nearest water are presented in Appendix 3 (p. 123). All trap-sites on transect B were within 15m of running water. Transect C had the greatest variation in distances from running water whilst transect D had the least with no trap-sites closer than 500m from any water. All but three trap-sites on transect E were within 5m of running water.

The number of rats caught, the corresponding percentage of captures and the water index for each species in each distance category are presented in table 3 (p. 30) The water indices, which indicate the relationship between captures and distance from water, are plotted in figure 8 (p. 31). Most ship rats were caught at trap-sites within 15m of water (table 3). Norway rats exhibited a strong preference for closeness to water (figure 8) with 92% of captures within 10m of water (table 3). Only one Norway rat, the single animal caught on transect D, was trapped further than 15m from water. Kiore exhibited the opposite relationship with water (figure 8), 77% being caught further than 20m from water (table 3).

3.2 Autopsies and Morphometrics

All 433 identified rats were autopsied to some extent. Incomplete autopsies resulted from partial scavenging of rats in the traps before collection.

The mean and range of weights of whole rats caught are given in table 4 (p. 32). Males were significantly heavier than females for both Norway rats ($p = .035$) and kiore ($p = .001$) but not for ship rats ($p = .212$).

Ship rat and kiore weight differed significantly with season ($p = .041$ and $p < .001$ respectively) but Norway rat weight did not. However, when each transect was looked at seasonal weight changes were not significant (Appendix 4, p. 124-125). Ship rats were heaviest in autumn and lightest in spring while kiore were heaviest in autumn and lightest in winter as indicated by parameter estimates (Appendix 4). Kiore weight also differed significantly with season when gender variation was incorporated ($p = .020$). Combining seasonal data, differences in weight on each transect were significant only for ship rats ($p = .048$). They were heaviest on transect E followed by transect B and then C and D as indicated by parameter estimates. The Scheffe test indicated that the only significant difference was that ship rats were lighter on transect D compared to on E (Appendix 4).

Results of multiway analysis of variance on weights and results of the Scheffe test (one-way analysis of variance) are presented as Appendix 4 and a comparison of weights of the three species from New Zealand is presented in Appendix 5 (p. 126).

TABLE 3: Captures at Known Distances from Water and Water Indices.

(a) Total trapping

		Ship rat			Kiore			Norway rat		
Distance Category		No.	%	W.I	No.	%	W.I	No.	%	W.I
(1)	0 - 5m	91	47	1.3	19	11	0.3	38	62	1.8
(2)	5 - 10m	36	19	1.4	8	4	0.3	18	30	2.1
(3)	10 - 15m	32	17	1.5	7	4	0.4	4	7	0.6
(4)	15 - 20m	0	0	0.0	7	4	2.0	0	0	0.0
(5)	>20m	33	17	0.4	138	77	2.0	1	2	0.05

(b) Transect Analysis

(i) Transect B

		Ship rat			Kiore			Norway rat		
Distance Category		No.	%	W.I	No.	%	W.I	No.	%	W.I
(1)	0 - 5m	12	22	0.9	1	20	0.8	7	26	1.1
(2)	5 - 10m	20	37	0.9	1	20	0.5	16	59	1.5
(3)	10 - 15m	22	41	1.1	3	60	1.7	4	15	0.4
(4)	No traps									
(5)	No traps									

(ii) Transect C

		Ship rat			Kiore			Norway rat		
Distance Category		No.	%	W.I	No.	%	W.I	No.	%	W.I
(1)	0 - 5m	15	31	1.3	10	19	0.8	7	100	4.3
(2)	5 - 10m	7	14	1.6	5	9	1.0	0	0	0.0
(3)	10 - 15m	10	20	2.2	4	7	0.8	0	0	0.0
(4)	15 - 20m	0	0	0.0	7	13	1.4	0	0	0.0
(5)	>20m	17	35	0.7	28	52	1.0	0	0	0.0

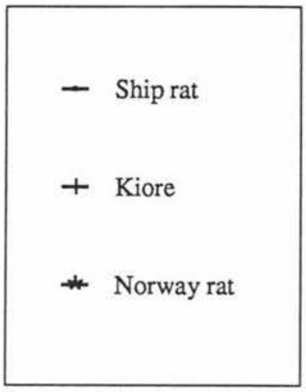
(iii) Transect D

All trap-sites were >20m from running water.

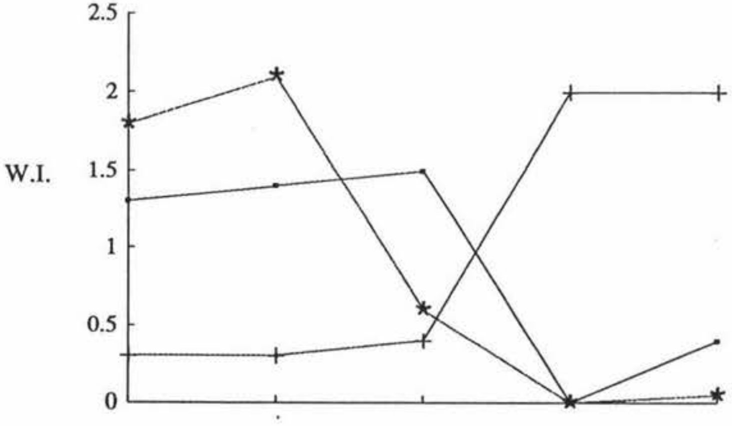
(iv) Transect E

		Ship rat			Kiore			Norway rat		
Distance Category		No.	%	W.I	No.	%	W.I	No.	%	W.I
(1)	0 - 5m	65	88	1.0	8	80	0.9	24	92	1.0
(2)	5 - 10m	9	12	1.0	2	20	1.8	2	8	0.7
(3)	no traps									
(4)	no traps									
(5)	no traps									

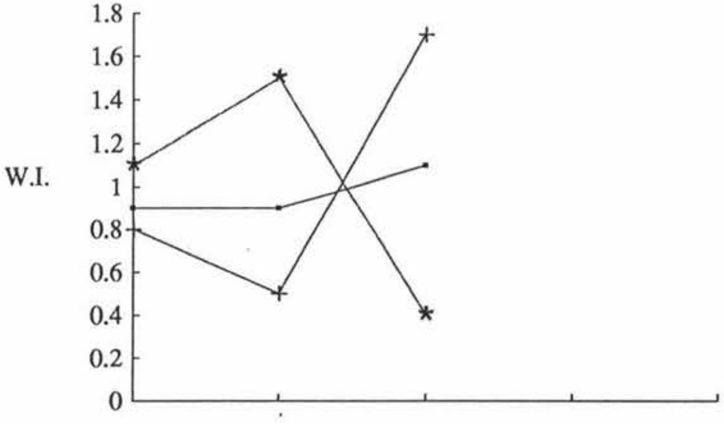
FIGURE 8: Relationship between Captures and Distance from Water



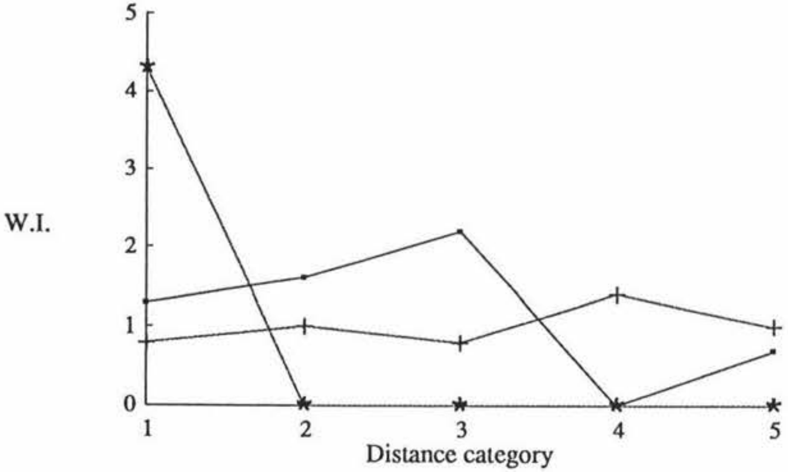
(A) Total Trapping



(B) Transect B



(C) Transect C



(D) Transect E

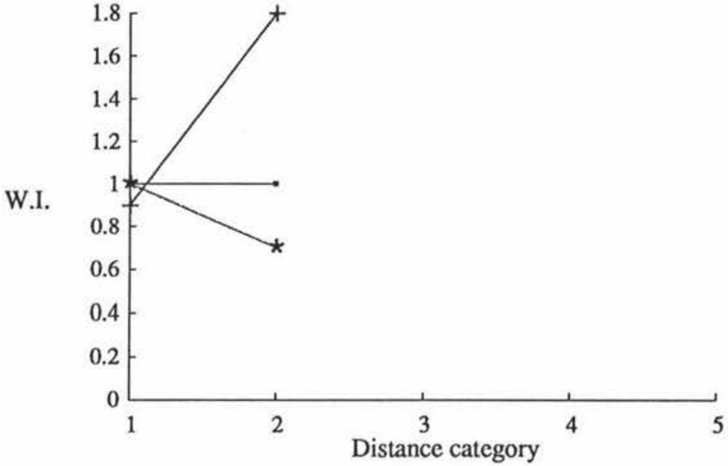


TABLE 4: Total Weight results

	Sex	n	$\bar{x}$ (g)	S.D	Max.	Min.
Ship rat	both	183	120.45	36.29	205.00	36.00
	M	96	124.17	38.67	205.00	40.00
	F	87	116.34	33.21	180.00	36.00
Kiore	both	170	63.39	13.79	97.00	30.00
	M	92	65.61	14.75	97.00	35.00
	F	78	60.77	12.14	87.00	30.00
Norway rat	both	61	180.21	66.25	288.00	28.00
	M	25	201.40	58.06	288.00	38.00
	F	36	165.50	68.33	280.00	28.00

TABLE 5: Total Head and Body Length results

	Sex	n	$\bar{x}$ (mm)	S.D	Max.	Min.
Ship rat	both	191	146.28	16.78	187.00	95.00
	M	100	147.06	17.56	187.00	105.00
	F	90	145.40	16.03	174.00	95.00
Kiore	both	175	117.20	11.59	144.00	83.00
	M	94	118.25	11.42	144.00	83.00
	F	81	115.98	11.72	141.00	92.00
Norway rat	both	61	164.17	29.42	201.00	85.00
	M	25	172.44	22.35	191.00	89.00
	F	36	158.57	32.60	201.00	85.00

The mean and range for head and body lengths of whole rats are presented in table 5 (p. 32). All three species showed a high degree of correlation between head and body length and weight: Norway rat r = .920, ship rat r = .857, kiore r = .726.

3.3 Reproduction

3.3.1 Sex Ratio

Sex ratios were equal for all species on all transects and in all seasons (table 6 p. 34)

3.3.2. Maturity

The maturity of 403 rats was recorded (170 ship rats, 173 kiore, 60 Norway rats). The proportions of immature rats were 35.3% of ship rat, 36.4% of kiore and 15% of Norway rat numbers (table 7, p. 35).

Marked seasonal changes in the percentage of immature rats were found each year of sampling (figure 9 p. 36). The greatest proportions of immature ship rats occurred in winter of 1984, 1985 and 1986 (1982 & 1983 trapping was incomplete) and the only summer occurrence of immature ship rats occurred in 1983 (figure 9). The highest proportions of immature kiore occurred in winter and spring of each year of trapping and immature Norway rats were only caught in winter and summer of 1983 and 1984 (figure 9).

Although there was a large overlap, mature rats were significantly heavier than immature rats for each species (table 8, p. 37).

The lightest males for each species with scrotal testes were, ship rats 74.0g, kiore 55.0g, and Norway rat 74.0g. The seasonal proportions of males of these minimum weights with scrotal testes are shown in figure 10a (p. 38). Seasonal changes in numbers of mature males of each species were recorded. Mature Norway rats were present in high proportions in all seasons, although peaks did occur in autumn and spring, mature male ship rats were common in all seasons except winter and mature male kiore were prominent only in autumn and summer (figure 10a).

The lightest mature females for each species were, ship rats 62.0g, kiore 35.0g, and Norway rats 112.0g. The seasonal proportions of mature females of these weights or heavier are shown in figure 10b (p. 38). The proportions of mature females varied little with season. There was a high capture rate of mature females compared with immature females.

3.3.3 Reproductive Activity

Very low numbers of pregnant rats were caught during the four and a half years of trapping (figure 11, p. 39).

TABLE 6: Sex Ratio

Ho: Captures of males and females did not differ from a 50:50 ratio

Species	Sex-Transect Association χ^2	Sex-Season Association χ^2	Sex Ratio χ^2
Ship rat	0.30	4.63	0.43
Kiore	3.05	3.03	0.68
Norway rat	2.17	2.51	1.64

N.B. all χ^2 tests not significant at 0.05 level

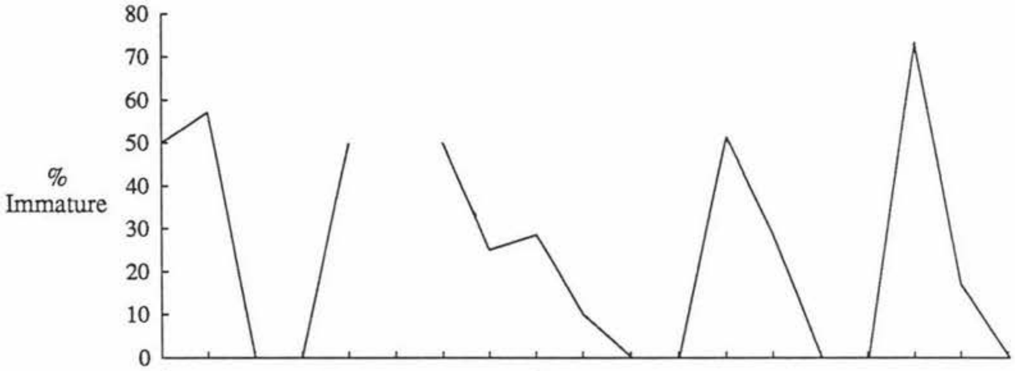
TABLE 7: Captures of Immature and Mature rats

		Males	Females	Totals
Ship rat	Immature	47	13	60
	Mature	45	65	110
	Total	92	78	170
Kiore	Immature	58	5	63
	Mature	35	75	110
	Total	93	80	173
Norway	Immature	4	5	9
	Mature	20	31	51
	Total	24	36	60

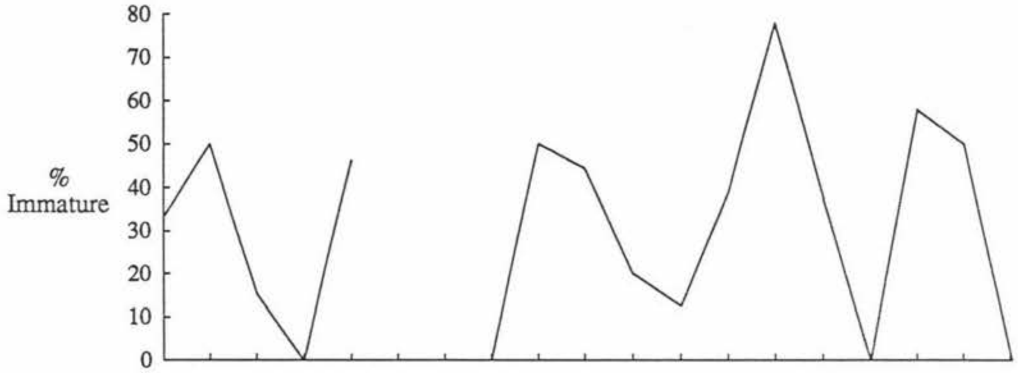
FIGURE 9: Seasonal changes in the Percentages of Immature rats

A = Autumn
W = Winter
Sp = Spring
Su = Summer

(a) Ship rat



(b) Kiore



(c) Norway rat

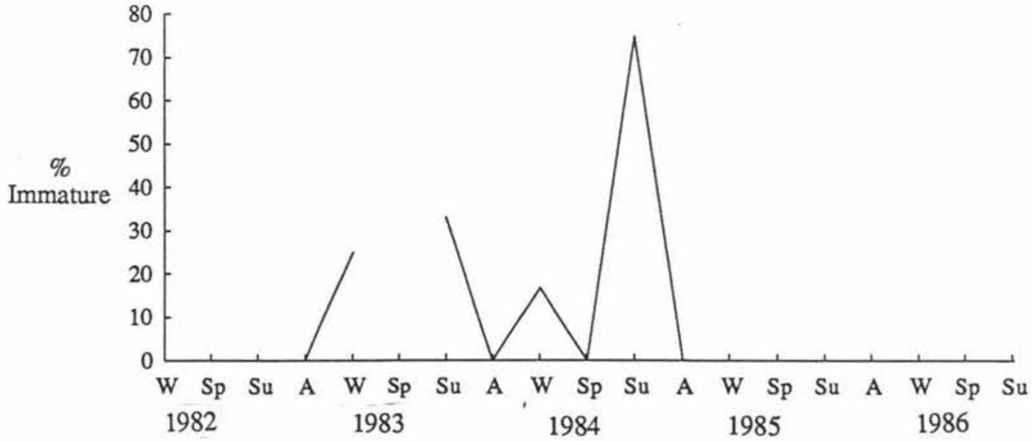


TABLE 8: Mean, maximum and minimum weights of immature and mature rats

	Maximum	Minimum	$\bar{x}$ (g)	Std dev.	Analysis of variance	
Ship rat					F	P
Immature	185.00	36.00	100.63	37.48	29.55	< .001
Mature	205.00	62.00	131.51	31.07		
Kiore						
Immature	90.00	30.00	56.56	11.80	25.55	< .001
Mature	97.00	35.00	67.08	13.37		
Norway rat						
Immature	236.00	28.00	87.11	84.17	30.40	< .001
Mature	288.00	74.00	196.00	47.93		

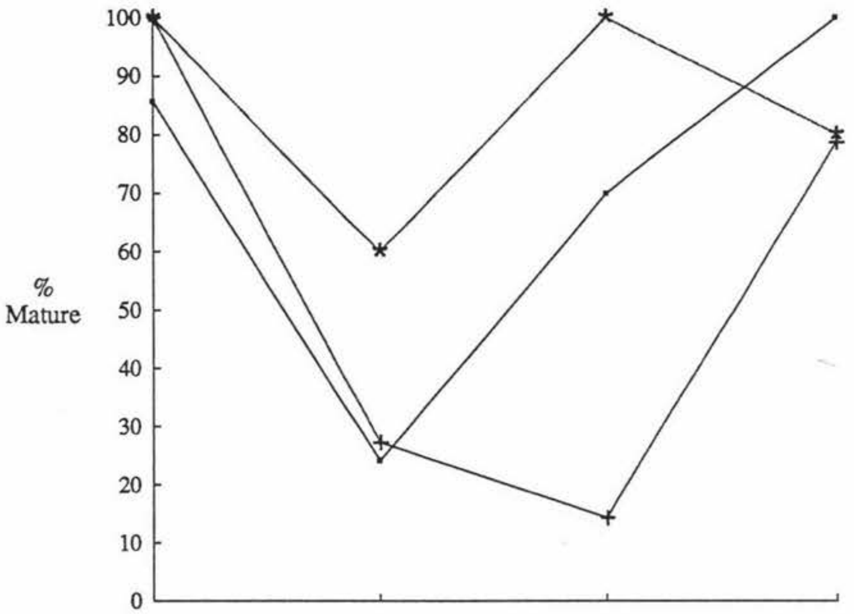
FIGURE 10: Seasonal changes in the Percentages of Mature rats

— Ship rat

+ Kiore

✳ Norway rat

(a) Males



(b) Females

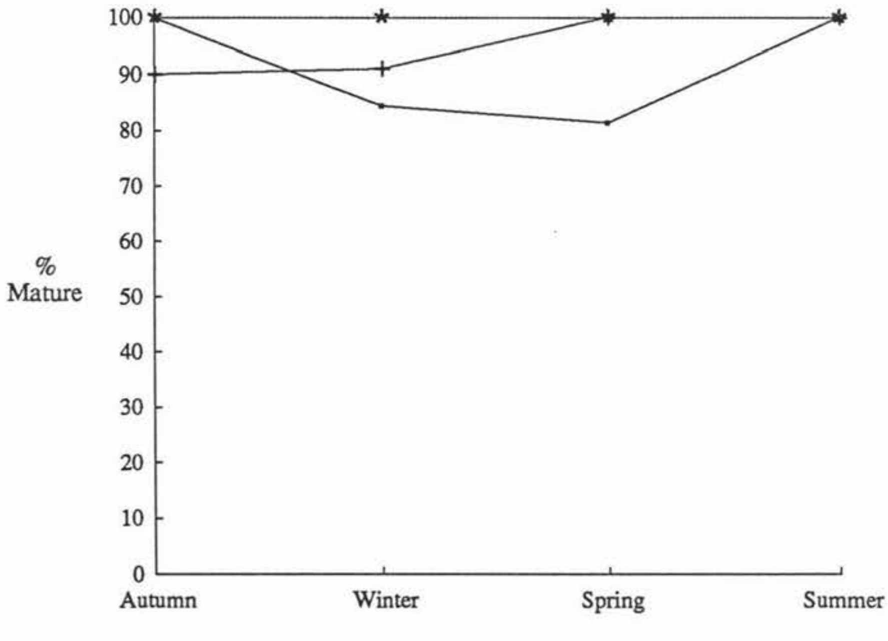
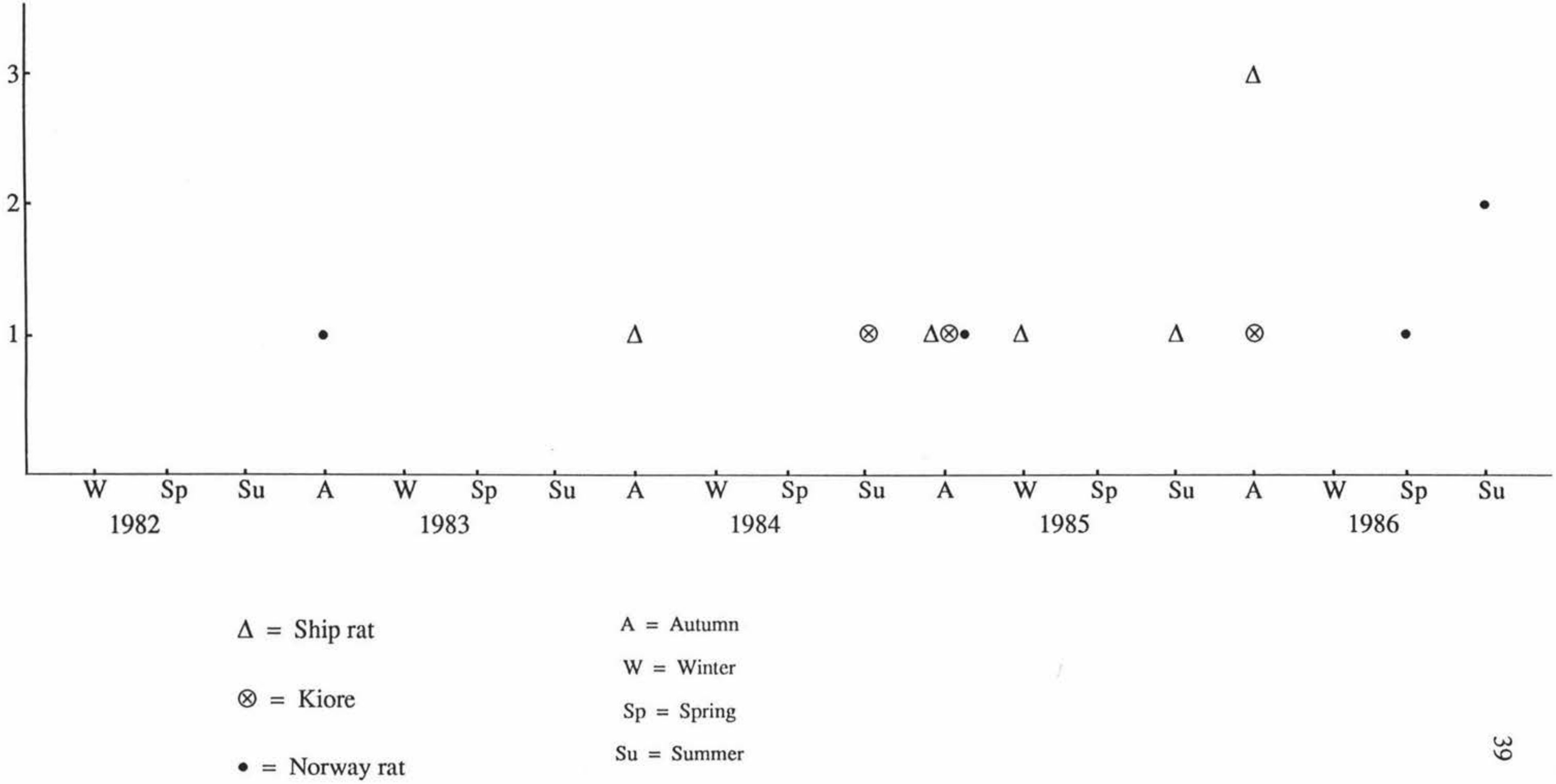


FIGURE 11: Captures of Pregnant Rats



Of the seven pregnant ship rats trapped (mean foetus number of 5.86 s.d = 2.54), none were caught in a spring trapping session. Three pregnant kiore were caught (mean foetus number of 4.67 s.d = 2.31) and only in summer and autumn sessions. Of the five pregnant Norway rats trapped (mean foetus number of 6.20 s.d = 2.17) none were caught in a winter trapping session. Calculation of mean foetus numbers are for all years combined for each species. Results from this study are compared to mean foetus numbers from other studies from the New Zealand region in Appendix 6 (p. 128).

The low numbers of pregnant rats caught resulted in a low recorded incidence of pregnancy (proportion of mature females pregnant in the population) for each species, although higher figures were recorded for ship rats and Norway rats in 1986 (table 9, p. 41). Such low observed pregnancy rates precluded the estimation of each species breeding season. An indication of the likely female annual productivity for each species may be derived using length of breeding seasons from other New Zealand studies. The length of breeding season is estimated at 240 days for ship rats (Daniel 1972, Best 1968, Innes 1977), 139 days for kiore (Dick 1985) and 251 days for Norway rats (Dick 1985). The annual incidence of pregnancy for the population, Ip, (i.e. frequency of litters per female per year) is first calculated by the following formula (Emlen and Davis 1948)

$$\text{Ip} = \frac{\text{incidence of pregnancy x length of breeding season}}{\text{duration of visible pregnancy}}$$

The frequency of litters per female per year is then multiplied by the mean foetus number to calculate the average female annual productivity. According to Best (1968) and Dick (1985), duration of visible pregnancy of ship rats and kiore is taken as being equal to that of Norway rats, i.e. 18 days (Emlen and Davis 1948). In this study the reproductive rates of all three species can only be calculated for 1985 and 1986 (table 10, p. 41).

3.4 Stomach Analysis and Diet

A total of 415 stomachs were examined. Unexamined stomachs are a consequence of rats being scavenged in the traps and in six cases, damage during storage of stomachs. Empty stomachs are included in the analyses and stomachs containing bait are included in the frequency of occurrence results, but are excluded from the volume estimates.

Frequency of occurrence of the six diet categories indicate that invertebrates and vegetation were eaten much more frequently by all three species than the other food categories (table 11, p. 42). Volume estimates indicate that invertebrates and vegetation also predominated quantitatively in the diet of each species (table 12a, p. 43).

TABLE 9: Incidence of Pregnancy

Year	Species	Incidence of Pregnancy	Comments
1983	N	.25	no trapping carried out in spring
1984	S	.08	state of maturity of 12 rats not recorded
1984	K	.06	state of maturity of 3 rats not recorded
1985	S	.12	
1985	K	.04	
1985	N	.125	
1986	S	.23	
1986	K	.10	
1986	N	.33	

TABLE 10: Annual Female Productivity

Species	Year	n	Litters/female/yr	$\bar{x}$ Foetus no.	Average female annual productivity
Ship rat	1985	3	1.6	5.0	8.00
	1986	3	3.06	6.3	19.23
Kiore	1985	1	0.31	6.0	1.86
	1986	1	0.77	6.0	4.66
Norway	1985	1	1.74	3.0	5.22
	1986	3	4.60	7.3	33.58

TABLE 11: Frequency of Occurrence of Food Categories

	Ship rat					Kiore					Norway rat				
Category	A	W	Sp	Su	Tot	A	W	Sp	Su	Tot	A	W	Sp	Su	Tot
Invert*	96	99	100	100	99	95	100	100	98	99	92	100	85	100	95
Vert**	8	10	0	4	7	0	0	0	0	0	17	24	31	6	18
Veg***	92	94	95	93	94	74	78	63	61	68	75	82	38	39	58
Wood	8	20	32	21	21	21	46	25	27	34	25	35	23	22	27
Fungus	13	6	5	21	9	0	3	0	2	2	8	0	0	0	2
Other	17	16	8	11	14	5	5	6	16	8	25	6	8	11	12

A = Autumn
W = Winter
Sp = Spring
Su = Summer

* Invert = Invertebrate
** Vert = Vertebrate
*** Veg = Vegetation

TABLE 12a: Mean Percentage Volume of Food Categories

Species	Invert*	Vert**	Veg***	Wood	Fungus	Other
Ship rat	38.5	1.5	53.3	0.6	0.8	4.8
Kiore	69.6	0.0	21.8	0.9	0.1	2.3
Norway rat	58.9	11.5	18.8	0.7	0.2	4.9

* Invert = Invertebrate

** Vert = Vertebrate

*** Veg = Vegetation

TABLE 12b: Seasonal Mean Percentage Volume of Food Categories

	Ship rat				Kiore				Norway rat			
Category	A	W	Sp	Su	A	W	Sp	Su	A	W	Sp	Su
Invert*	42.9	32.8	43.1	48.8	41.1	65.2	71.9	87.9	51.6	50.7	51.2	75.9
Vert**	1.8	2.5	0.0	0.0	0.0	0.0	0.0	0.0	16.2	3.4	27.3	4.9
Veg***	42.1	58.1	52.9	46.5	48.2	26.5	12.5	9.1	22.8	44.5	4.0	3.0
Wood	0.0	0.4	1.5	0.3	0.0	1.8	0.4	0.2	0.0	1.0	0.8	0.8
Fungus	1.1	0.5	0.4	2.2	0.0	0.1	0.0	0.0	0.8	0.0	0.0	0.0
Other	7.9	5.8	2.1	2.3	0.2	2.3	2.8	2.8	8.6	0.3	0.0	9.8

A = Autumn

W = Winter

Sp = Spring

Su = Summer

* Invert = Invertebrate

** Vert = Vertebrate

*** Veg = Vegetation

No seasonal variation was recorded in the frequency of occurrence of invertebrates and vegetation for ship rats (table 11), although small seasonal changes in the volume estimates indicate a slight seasonal shift in the proportions eaten. Volume of vegetation peaked in winter whilst invertebrate volume was lowest in winter and highest in summer (table 12b, p.43). For kiore, invertebrates were commonly eaten in all seasons but the volume consumed was greatest in summer and smallest in autumn. Frequency of occurrence of vegetation was highest in autumn and winter and lowest in spring and summer (table 11). Volume of vegetation peaked in autumn and was lowest in summer (table 12b). Norway rats commonly ate invertebrates in all seasons, although less often in spring (table 11), and volume eaten peaked in summer. Vegetation was consumed more often in autumn and winter than in spring and summer (table 11). Volume of vegetation eaten by Norway rats peaked in winter and was markedly lower in spring and summer (table 12b).

3.4.1 Invertebrates

Invertebrates dominated kiore and Norway rat diet in both frequency of occurrence and volume (table 11, table 12a). Invertebrates were the most common diet item in ship rat stomachs (table 11), although the average percentage volume eaten was less than that for vegetation (table 12a).

Wetas (Orthoptera) were by far the most frequent invertebrate type eaten by ship rats, occurring in very high frequencies in all seasons (table 13, p.45). The next most common invertebrates were Opiliones, followed by centipedes (Chilopoda), then unidentified beetles (Coleoptera), spiders (Araneida) and Lepidoptera larvae (table 13). The frequency of occurrence of Opiliones and beetles dipped in spring whereas spiders and Lepidoptera larvae peaked in autumn and summer. Centipedes were eaten in similar frequencies in all seasons (table 13).

Wetas, followed by spiders were the most common invertebrates eaten by kiore (table 13). Weta occurrence peaked in summer whereas the frequency of occurrence of spiders was highest in autumn and winter. Centipedes were the next most common, followed in descending order of occurrence by earthworms (Terricolae), Opiliones, Lepidoptera larvae, carabid beetles (Carabidae) and amphipods (Amphipoda) (table 13).

Freshwater crayfish (*Paranephrops zealandicus*) (Decapoda) were by far the most common food eaten by Norway rats with peak occurrence in autumn, although high frequencies were recorded in each season (table 13). Only six other invertebrate types were commonly eaten. These were, in decreasing order of frequency, Opiliones, wetas, spiders, carabid beetles, stonefly larvae (Plecoptera) and other beetle families (table 13). Seasonal changes in frequencies indicate wetas and other beetle families were eaten predominantly in autumn and summer, Opiliones and spiders were eaten

TABLE 13: Frequency of Occurrence of Invertebrates

	Ship rat					Kiore					Norway rat				
Invert.	A	W	Sp	Su	Tot	A	W	Sp	Su	Tot	A	W	Sp	Su	Tot
Orthoptera	83	84	92	86	85	79	69	72	86	75	42	18	23	50	33
Araneida	42	13	16	43	22	63	66	50	50	59	25	24	15	22	22
Opilione	29	27	19	36	27	37	19	19	39	31	58	41	8	39	37
Chilopoda	29	24	22	21	24	26	42	47	20	36	-	6	-	-	2
Terricolae	-	5	3	11	5	21	38	47	32	36	-	6	8	6	5
Phasmatodea	8	19	11	18	16	5	3	-	-	2	-	-	-	-	-
Amphipoda	4	4	11	7	6	-	28	34	16	23	-	6	-	-	2
Blattodea	17	7	27	7	12	11	14	16	34	19	-	-	-	6	2
Gastropoda															
(slug)	-	7	11	11	8	16	5	-	2	5	-	-	-	-	-
(snail)	8	7	24	11	11	-	5	3	5	4	-	-	-	-	-
Coleoptera															
Unidentified	38	21	14	29	23	16	20	22	9	18	25	6	-	17	12
Carabidae	4	7	3	32	10	21	14	28	41	24	17	-	-	50	18
Scarabidae	-	1	3	11	3	-	-	-	7	2	-	-	-	28	8
Curculionidae	-	2	5	-	2	-	-	-	2	1	-	-	-	-	-
Larvae	17	2	3	-	4	5	3	3	5	4	8	-	8	-	3
Diptera L.*	4	8	8	7	8	-	8	9	2	6	-	-	8	-	3
Lepidoptera L.	46	15	11	32	21	32	16	28	41	27	-	12	8	11	8
Plecoptera L.	-	-	-	-	-	-	-	-	-	-	8	29	15	-	13
Unidentified L.	8	7	-	14	7	5	8	3	7	6	8	6	-	-	3
Decapoda	-	-	-	-	-	-	-	-	-	-	67	59	54	39	53
Other	-	2	5	4	3	-	1	-	5	2	17	-	8	-	5
Unidentified	4	2	5	-	3	5	1	3	2	3	-	-	8	6	3

A = Autumn
W = Winter
Sp = Spring
Su = Summer

* L. = larvae

least in spring, carabid beetles were only eaten in autumn and summer and stonefly larvae were commonly eaten in winter and spring (table 13).

Occurrence of invertebrates in the diet of each species varied markedly. Stick insects (Phasmatodea) and snails (Gastropoda) were eaten much more frequently by ship rats than by either kiore or Norway rats (table 13). Snails were identified by their soft bodies only, as no shell fragments were found in any stomachs. Amhipods were much more common in kiore stomachs than in either ship rat or Norway rat diet whereas Lepidoptera larvae, cockroaches (Blattodea) and centipedes, were eaten most often by ship rat and kiore (table 13). The aquatic invertebrates, freshwater crayfish and stonefly larvae, were taken only by Norway rats. Adult beetles were identified as Carabidae, Scarabidae, Curculionidae and other unidentified families. Carabidae were the most common adult form of beetle eaten by all species (table 13). Weevils (Curculionidae) were eaten infrequently by ship rats and kiore and Scarabid beetles (Scarabidae) were found mainly in Norway rat stomachs (table 13). Frequencies of all invertebrates eaten are presented in table 13, (p. 45).

3.4.2 Vegetation

Vegetation occurred less often than invertebrates in the diet of each rat species (table 11). It was a lower mean percentage volume than invertebrates in kiore and Norway rat diet, but provided the greatest mean percentage volume for ship rat diet (table 12a). Vegetation comprised a much larger proportion of ship rat diet than in either of the other two species (table 12a).

Cuticle analysis revealed a tremendous diversity of plant species and parts were eaten by rats. A total of 100 plant categories were established, of which 54 species were identified. Another five genera were identified but none to species level. Nine categories of unidentified material were established. These were fruits, leaves, flowers, fern scales, liverworts, seeds and/or rhizomes, and X, Y and Z. Unidentified seeds and/or rhizomes included items that were either seed or rhizome but which could not be determined. It was not possible to be more specific because of the lack of distinguishing features of most seeds and rhizomes after maceration. Thorough mastication by rats also made visual identification impossible before cuticle analysis procedures. Unidentified X, Y, and Z were regularly occurring cuticles and were therefore kept separate. Attempts were made to identity them by continually testing new plants and plant parts collected during each trip, but without success.

The frequency of occurrence of plants and plant parts eaten are presented in table 14a & b (p. 47-49).

TABLE 14a: Frequency of Occurrence of Plant Items

Plant	Common name	Part eaten	Ship rat	Kiore	Norway rat
Asplenium spp.	spleenworts	leaf	3	0	0
Bazzania involuta	a liverwort		5	1	2
Blechnum discolor	crown fern	leaf	2	1	0
Blechnum nigrum	black hard fern	leaf	1	0	0
Blechnum spp.	hard ferns	rhizome	6	7	2
Carpodetus serratus	putaputaweta	leaf/stem	2	0	2
Coprosma colensoi		leaf	1	0	2
Coprosma foetidissima	stinkwood	bark	2	0	0
		fruit	7	0	2
		leaf	3	0	0
Coprosma rhamnoides		bark	3	0	2
		leaf	2	0	0
Corybas rivularis	dancing spider orchid	plant	1	0	0
Cyathodes empetrifolia	a dwarf heath	fruit	3	8	0
		leaf	2	2	0
		seed	0	1	0
Cyathodes juniperina	prickly mingimingi	fruit	16	3	0
		leaf	9	5	0
Cyathophorum bulbosum	a moss	leaf/stem	13	3	17
Dacrydium cupressinum	rimu	fruit	22	12	7
		leaf	16	5	7
		seed	8	5	8
Dracophyllum longifolium	inaka	flower buds	1	0	0
		leaf/leaf bases	2	4	2
		pods	0	1	0
Empodisma minus	wire rush	leaf	0	0	2
Ehrharta diplax	bush rice grass	stem bases	4	0	2
Gahnia procera	gahnia	leaf/leaf bases	4	8	0
Gaultheria antipoda	bush snowberry	fruit	4	0	2
		leaf	4	1	0
		seed	1	0	0
		stem	2	0	0
Gleichenia dicarpa	tangle fern	leaf	0	1	0
Grammitis billardierei	a finger fern	leaf	1	0	0
Grammitis rigida	a finger fern	leaf	0	1	0
Griselinia littoralis	broadleaf	leaf	2	0	0
		stem/stembuds	8	0	3
Halocarpus biformis	pink pine	fruit	4	4	5
		leaf	3	5	3
		seed	1	2	0
Hymenophyllum spp.	filmy ferns	leaf	1	0	0
Hypolepus spp.	ferns	leaf	1	0	0
Hypopterygium rotulatum	a moss		2	0	2
Juncus spp.	a rush	leaf	0	1	0
Korthalsella salicornioides	dwarf mistletoe	plant	26	3	0
Lepidothamnus intermedius	yellow silver pine	fruit	10	7	0
		leaf	11	12	10
		seed	3	8	0
Lepidozia pendulina	a liverwort		2	1	0
Lepidolaena clavigera	a liverwort		1	2	0

TABLE 14a continued

Plant	Common name	Part eaten	Ship rat	Kiore	Norway rat
Leptospermum scoparium	manuka	bark	4	2	3
		leaf	14	5	13
		pod	2	1	0
lichen			2	0	3
Luzuriaga parviflora	lanternberry	fruit	3	1	0
		leaf	12	0	3
Lycopodium ramulosum	carpet clubmoss	repr. cone	0	1	0
Lycopodium varium	hanging clubmoss	leaf	1	0	0
Lyperanthus antarcticus	horizontal orchid	leaf	2	1	0
Metrosideros umbellata	southern rata	flower	1	0	0
		fruit	1	0	0
		leaf	6	0	13
Myrsine australis	red mapou	leaf	0	0	2
Myrsine divaricata	weeping mapou	fruit	2	0	0
Neomyrtus pedunculata	rohutu	fruit	1	0	0
		seed	2	0	0
Nertera depressa	a herb	fruit	1	0	0
Oreobolus pectinalis	comb sedge	leaf	1	0	2
Pentachondra pumila	a dwarf heath	fruit	2	2	2
		leaf	0	1	0
Phormium cookianum	mountain flax	pod	1	0	0
Phymatosorus diversifolius	hounds tongue fern	leaf	3	0	2
Plagiochila lyallii	a liverwort		1	1	0
Podocarpus hallii	thin-bark totara	fruit	2	0	2
		leaf	4	2	3
		seed	1	0	5
Prumnopitys ferruginea	miro	fruit	31	1	12
		leaf	3	1	7
Pseudopanax simplex	haumakaroa	leaf	5	0	2
Pterygophyllum quadrifarium	a moss	leaf	2	1	0
Senecio lyallii	yellow snow groundsel	rhizome	0	1	0
Senecio renoldii	muttonbird scrub	leaf	2	0	0
Thelymitra hatchii	a blue sun orchid	leaf	1	0	0
Thelymitra pulchella	a blue sun orchid	leaf	1	0	0
Thelymitra venosa	veined sun orchid	leaf	1	0	0
		rhizome	1	0	0
Tylimanthus saccatus	a liverwort		2	1	0
Uncinia spp.	hooked sedges	seed	0	0	2
		stem	0	3	0
Weinmannia racemosa	kamahi	leaf	5	1	8
Unidentified fern scales			1	1	2
Unidentified flowers			2	1	3
Unidentified fruit			5	1	8
Unidentified leaves			16	1	8
Unidentified liverworts			6	7	3
Unidentified mosses			6	0	2
Unidentified seed/rhizome			32	28	25
X			3	8	5
Y			4	7	0
Z			8	0	2
Diversity (number of plant groups eaten)			88	53	45

TABLE 14b: Frequency of Occurrence of grouped Plant Items

Plant part	Ship rat	Kiore	Norway rat
Fruit and seed (includes unidentified seed/rhizome)	69	38	32
Leaf material (includes leaf/leaf buds/stems)	78	48	43
Rhizomes (identified)	10	14	2
Miscellaneous	10	3	10

Ship rats ate the greatest range of plants, consuming 88 out of the 100 types found in all stomachs. Kiore and Norway rats' were markedly less diverse (table 14b) . Although a large number of plants and plant parts were eaten, few were utilized often by any species.

Unidentified seed and/or rhizome was the most frequently occurring plant category for all rats. Its occurrence in kiore diet was more than double any other plant item.

Fruits were more prominent in ship rat diet than in either of the other species. Miro fruit was by far the most common identified plant item eaten by ship rats followed by *Korthalsella salicornioides*, rimu and *Cyathodes juniperina* fruit and rimu leaf. Rimu and *Cyathodes empetrifolia* were the fruits most often eaten by kiore and miro was the only fruit consumed to any extent by Norway rats.

A large variety of vegetative parts were identified but few were consistently eaten by any rat species. Those that were, included rimu and lantern berry leaves and broadleaf stem buds and stems by ship rats, rata leaves by Norway rats, and manuka leaves by ship rats and Norway rats. Yellow-silver pine leaves were also regularly eaten by all three species. The dwarf mistletoe *Korthalsella salicornioides*, which parasitizes manuka, was the third most frequent plant item eaten by ship rats. It occurred occasionally in kiore diet but not at all in Norway rat diet.

Liverworts were infrequently eaten by all species but noticeably less so by Norway rats.

Mosses were predominantly found in ship rat stomachs, although one moss in particular, *Cyathophorum bulbosum*, was favoured by both ship and Norway rats. For Norway rats this was the second most common plant item eaten.

The most frequently occurring rhizomes were those of *Blechnum* spp. and they were eaten mainly by ship rats and kiore.

The frequency of occurrence of other plants and plant parts can be found in table 14.

Cuticle Analysis Additions

The gut contents of several wetas produced the following list of plants:
Korthalsella salicornioides, totara leaf, rata leaf, rata fruit (unripe), several mosses and several liverworts.

The size of cuticles found in weta guts was consistent,with none greater than 500 μ m except for the occasional stalk of a liverwort or moss. The gut contents of the single stick insect analyzed, contained exclusively totara leaves and the cuticle sizes were much larger than wetas.

Several plant items only occurred as cuticle sizes < 500 µ m. All of these plant items were leaf cuticles apart from one fruit (unripe rata capsules) and they are presented in table 15 (p. 52).

Some plant items were only ever scored as present though never abundant. All these cuticles were leaf material (table 15). Furthermore some items either occurred as single large pieces, i.e. scored only as present, or as sizes that were consistent with weta cuticles. Summaries of this are presented in table 15.

3.4.3 Vertebrates

Vertebrate remains were found only in ship rat and Norway rat stomachs (table 11). The volume eaten by Norway rats was much greater than that by ship rats with peaks occurring in autumn and spring (Table 12a & b). A total of six ship rat (7%) and four Norway rat stomachs (7%) contained remains of birds. Of the bird remains only kiwi was identified and these occurred in a Norway rat stomach from transect E. Lizard (Leiolopisma spp.) remains were found in two Norway rat stomachs (3%). The remaining vertebrate occurrences were recorded as mammal and were ether possum, cat (*Felis catus*) or rat.

3.4.4 Other Diet Categories

Although fragments of wood were often found in the stomachs of all species (table 11) the amount eaten, was very small (figure 12a & b). Fungus did not occur often (table 11) and made up a very small proportion of the diet for all species (table 12a). The category 'other' included a small amount of unidentified material, soil, and, in one case, a length of string. Small volumes of rat fur not associated with flesh thus presumed to be consumed while grooming or fighting were also included. This category occurred most frequently and with greatest percentage volume in Norway rat stomachs (table 11 & 12a). Bait was consumed rarely by Norway rats and most frequently by kiore (table 11).

3.5 Diet Analysis

3.5.1 Species Differences

Analysis of differences in the percentage volume of diet, comprising the six food categories, invertebrate, vertebrate, vegetation, wood, fungus and other, between species, transect, season and weight class was attempted using multivariate analysis of variance (SPSSX MANOVA). Extreme deviation from homoscedasticity (Appendix 7, p 129) rendered the results unreliable. Data transformations could not alleviate this problem. Even so the MANOVA results have been included as appendix 7.

Using the percentage occurrence data, the hypothesis that diet composition differed between species was tested using the Chi-square test of homogeneity (Dixon and

TABLE 15: Cuticle Analysis Additions

(a) Cuticles Weta Size Only

Plant	Common name	Part
Podocarpus hallii	totara	leaf
Weinmannia racemosa	kamahi	leaf
Blechnum spp.	hard ferns	leaf
Blechnum discolor	crown fern	leaf
Psedopanax simplex	haumakaroa	leaf
Hymenophyllum spp.	filmy ferns	leaf
Bazzinia involuta	a liverwort	plant
Gaultheria antipoda	bush snowberry	leaf
Grammitis rigida	a finger fern	leaf

(b) Cuticles Weta Size or Present Only

Plant	Common name	Part
Metrosideros umbellata	southern rata	leaf
Dracophyllum longifollium	inaka	leaf
Cyathodes empetrifolia	a dwarf heath	leaf

(c) Cuticles Present Only

Plant	Common name	Part
Pruminoptyus feruginea	miro	leaf
Grammitis billiardii	a finger fern	leaf
Dracophyllum longifolium	inaka	pods

Massey 1969). The original 126 diet items comprising 100 plant, 22 invertebrate, vertebrate, wood, fungus and other food items were amalgamated into a total of 49 diet categories (Appendix 8, p. 130). This was necessary to accommodate the requirements of Chi-square analysis of having fewer than 20% of cells with an expected frequency less than five and none less than one (Sokal and Rolhf 1969). Diet was found to be significantly different between the three species $\chi 2 = 890.195$, d.f = 96, $p < 0.001$.

Discriminant function analysis (SPSSX) was used to further investigate the differences in diet composition between species. Stepwise analysis retained 61 diet items which provided good discrimination (90.12% correct classification) of the three species (figure 12, p. 54). Repeating the analysis on a random subsample of half the data and applying the discrimination function to the remaining data resulted in a correct classification rate of 74.11% indicating that the discrimination was robust.

Examination of the correlation of individual diet items with discriminant functions revealed that presence of stick insects, miro fruit and broadleaf stems/stem buds, particularly characterized ship rat diet. For kiore the presence of spiders, earthworms and amphipods and the absence of vertebrate were the most distinguishing diet items whereas the presence of freshwater crayfish, absence of *Korthalsella salicornioides* and lack of wetas were the most characteristic of Norway rat diet (figure 12).

3.5.2 Differences between Sex

As there was no difference in the sex ratio of each species the hypothesis that diet composition differed with sex was tested on all species combined. No significant differences were found $\chi 2 = 54.465$, d.f = 48, $p = 0.242$.

Because species differences in diet were found the effects of transects, seasons and weight class were tested separately for each species using the Chi-square homogeneity test. These tests required further amalgamation of diet categories. The categories used and their relative frequencies of occurrence are presented in Appendix 9 (p. 131-133), 10 (p. 134) and 11 (p. 135).

3.5.3 Variation among Transects

Because transects B and E were similar mature kamahi-podocarp forests and few kiore were caught on them, they have been combined for the kiore diet analysis. In the case of Norway rats, transect D has been omitted because only one Norway rat was caught there. Significant differences in diet between transects were found only for ship rats and Norway rats ($\chi 2 = 165.314$, d.f = 75, $p < 0.001$ and $\chi 2 = 35.076$, d.f = 14, $p = 0.0014$ respectively).

FIGURE 12: Description of each species diet by discriminant function analysis

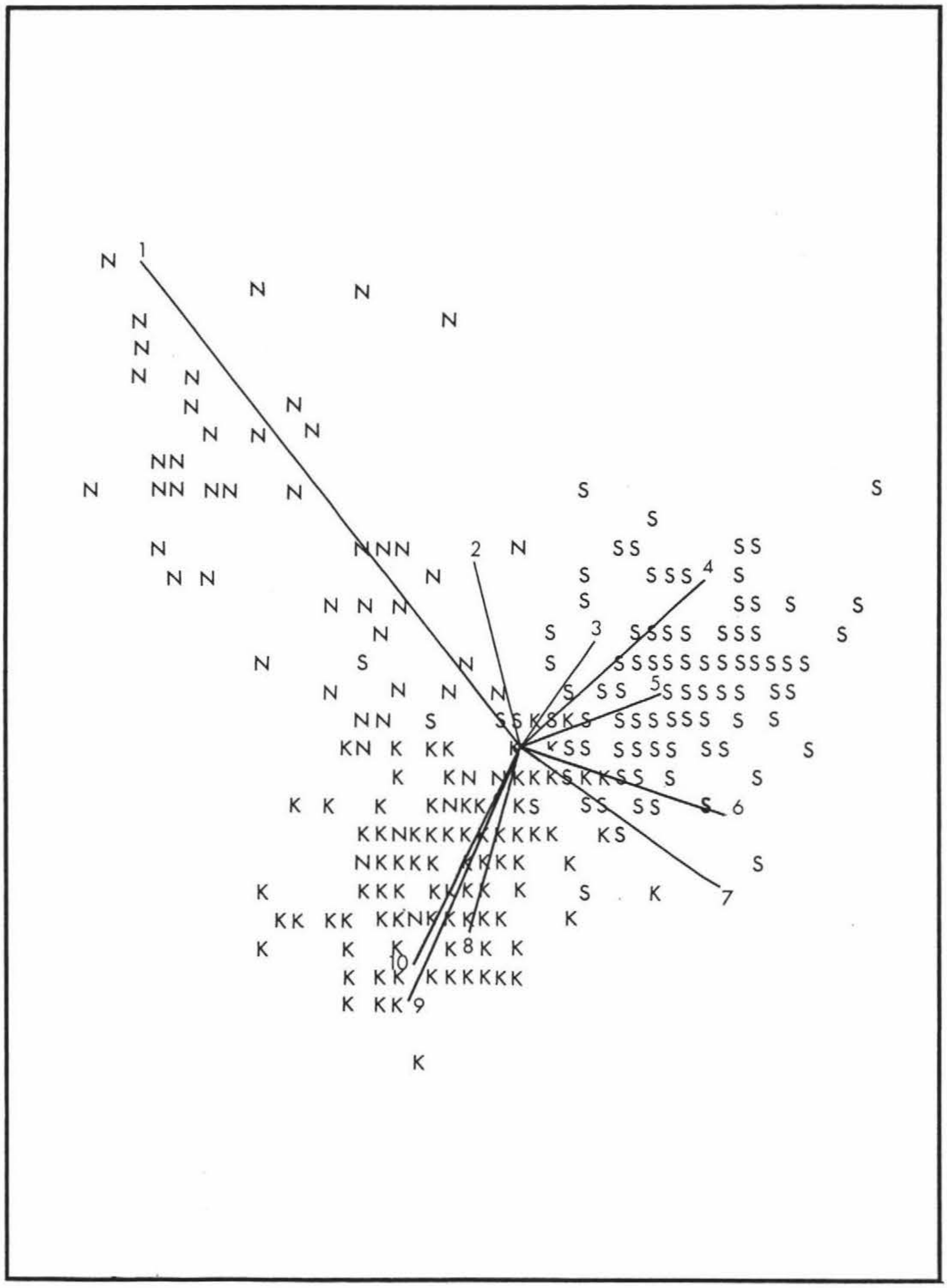
Each rat stomach sample is plotted against the two discriminant functions defined by the presence of 61 diet items.

N = Norway rat S = Ship rat K = Kiore

Also plotted are the ten diet items with the highest correlations with either discriminant function,

1 = Decapoda
2 = Vertebrate
3 = *Griselinia littoralis* stems/stem buds
4 = *Prumnopitys ferruginea* fruit
5 = Phasmatodea
6 = *Korthalsella salicornioides*
7 = Orthoptera
8 = Amphipoda
9 = Terricolae
10 = Araneida

The direction of the vector indicates the nature of its discriminatory power, eg. the vector for Decapoda points towards the Norway rat group, indicating that the presence of this diet item is a good character for distinguishing the diet of Norway rats from that of the other species.


N
S
K
1
2
3
4
5
6
7
8
9
10

Examination of the relative occurrences of diet items shows those items that caused the greatest variation between transects. For ship rat, these were leaf material, moss, miro and *Cyathodes juniperina* fruit and 'other fruit' (Appendix 9a). Of the invertebrates stick insects and beetles showed the greatest variation between transects (Appendix 9a).

For Norway rats variation between transects was reasonably marked for all categories except Opiliones (Appendix 10a). Fruit and beetles showed the greatest variation. Fruit most often occurred in Norway rat diet on transect B and to a lesser extent on E. Beetles were most common in diet on transect E. Aquatic invertebrates, freshwater crayfish and stonefly larvae, were also much more frequent on transects B and C than on E (Appendix 10a).

3.5.4 Seasonal Differences

Seasonal differences in diet were significant for all species of rat:

(1) Ship rat $\chi 2 = 234.939$, d.f = 75, $p < 0.001$

The diet categories that caused most of the seasonal variation in ship rat diet were rimu, miro and other fruit, other leaf, *Korthalsella salicornioides*, seeds, other plant items, moss, beetles, Lepidoptera larvae and other invertebrates (Appendix 9b). The fruits were all more frequent in autumn and winter as were seeds and *Korthalsella salicornioides*. 'Other plant items' showed a marked increase in frequency in spring and summer. Moss was mainly taken in summer. Beetle consumption also peaked in summer, Lepidoptera larvae were most commonly eaten in autumn while other invertebrates were most frequent in spring and summer (Appendix 9b).

(2) Kiore $\chi 2 = 109.302$, d.f = 45, $p < 0.001$

The seasonal frequency of occurrence of diet items for kiore indicate a general trend of greater consumption of plant material in autumn and winter and invertebrates in spring and summer (Appendix 11). Seasonal variation in diet categories were mainly caused by leaf material, which had a high frequency of occurrence in winter and spring, seed which occurred most often in autumn and fruit which predominantly occurred in autumn and to a lesser extent in winter and summer (Appendix 11). Of the invertebrates, amphipods, earthworms and centipedes showed the greatest variation with season. They were all most commonly taken in spring. Carabid beetles and Lepidoptera larvae were most frequently eaten in summer (Appendix 11).

(3) Norway rat $\chi 2 = 77.407$, d.f = 21, $p < 0.001$

Seasonal variation in Norway rat diet shows similar patterns to kiore with the two vegetation categories eaten most often in autumn and winter, although plant material was frequently eaten in all seasons. The invertebrate categories generally indicate greater consumption in spring or summer, although this varied for each type. For example the frequency of beetles peaked in autumn and summer (Appendix 10b).

3.5.5 Differences between Weight Classes

Significant differences in diet between weight classes were found only for Ship rats ($\chi 2 = 112.667$, d.f = 75, $p = 0.0032$). Small differences between weight classes were revealed for all categories (Appendix 9c). Leaf material was more often consumed by weight classes 1, 2, and 3 compared with class 4, and a higher frequency of occurrence of beetles was recorded in weight class 4 compared with the other three classes.

3.6 Parasites

No stomach nematodes or other stomach parasites were found.

I identified the fleas found on the rats from my 1986 rat trapping programme and Dr. W.A.G. Charleston (Massey University) and Professor R.L.C. Pilgrim (University of Canterbury) checked samples of them. Two species were found: *Pygiopsylla hoplia* and *Nosopsyllus fasciatus*. These have previously been recorded from Stewart Island (Smit 1979).

3.7 Food Availability

3.7.1 Invertebrate Sampling

Pitfall Trapping

A total of 1092 invertebrates were caught on the four transects. The greatest number were captured on transect B, followed in decreasing order by D, E and C (table 16, p. 57). Overall, autumn trapping yielded the greatest number of invertebrates; the lowest number were caught in winter (figure 13a, p. 58). This trend was displayed in trapping results from all transects (figure 13b, p. 58). Results of pitfall trapping are presented in tables 16, figures 13a & b, and 14, (p. 59)

Amphipoda

Amphipods were the most abundant invertebrate captured both in total and on each transect (table 16). The greatest number were caught on transect B followed by E, D and then C. On transect B, highest numbers were caught in summer and spring whilst on C, higher numbers were caught in autumn, spring and summer. On transect D, numbers were highest in winter followed by spring, autumn and summer. Most amphipods were trapped in autumn on transect E (table 16).

Terricolae

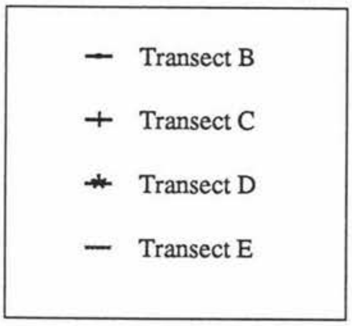
Earthworms were caught only on transects C, D, and E. Highest numbers occurred on D, mainly in winter (table 16). On C, low numbers were caught in autumn and summer and on transect E, they were only caught in very low numbers in summer. No earthworms were captured in spring on any transect (table 16).

TABLE 16: Seasonal Captures of Pitfall Trapped Invertebrates

	B					C					D					E					
INVERTEBRATE	A	W	Sp	Su	Tot	A	W	Sp	Su	Tot	A	W	Sp	Su	Tot	A	W	Sp	Su	Tot	Tot
Amphipoda	19	16	37	53	125	15	9	17	16	57	15	31	21	14	81	34	15	10	23	82	345
Terricolae	0	0	0	0	0	1	0	0	2	3	1	11	0	1	13	0	0	0	1	1	17
Acarina	5	1	12	6	24	6	1	5	1	13	0	0	4	0	4	4	6	6	2	18	59
Araneida	12	9	9	12	42	12	3	6	8	29	12	7	19	26	64	13	7	4	11	35	170
Opilione	2	0	2	2	6	2	0	0	4	6	1	0	1	9	11	0	0	0	1	1	26
Pseudoscorpione	1	0	1	0	2	0	0	0	0	0	1	1	0	1	3	0	0	0	0	0	5
Carabidae	45	0	16	21	82	10	0	10	7	27	18	0	12	7	37	16	2	9	17	44	190
Curculionidae	0	0	1	3	4	1	0	7	7	15	2	0	5	3	10	2	0	3	2	7	36
Other Coleoptera	17	3	9	3	32	23	0	7	5	35	8	1	0	2	11	6	2	4	2	14	92
Coleoptera larvae	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Chilopoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Diploda	0	0	0	0	0	1	0	0	3	4	0	2	1	1	4	0	1	0	2	3	11
Diptera adult	0	0	2	1	3	2	0	0	4	6	0	0	0	1	1	1	0	2	0	3	13
Diptera larvae	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Hemiptera	0	0	0	0	0	1	1	0	0	2	1	0	0	0	1	0	0	0	0	0	3
Hymenoptera	0	0	1	0	1	0	0	2	1	3	12	0	5	6	23	2	0	1	0	3	30
Isopoda	0	0	2	0	2	1	1	0	0	2	0	0	0	0	0	0	0	2	0	2	6
Lepidoptera	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2
Gastropoda (snail)	0	1	0	2	3	1	0	0	0	1	1	0	0	0	1	0	0	0	1	1	6
Orthoptera	0	0	0	0	0	0	0	0	0	0	3	3	7	1	14	0	0	0	0	0	14
Planaria	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1
Unidentified	8	2	2	0	12	7	2	3	1	13	11	3	4	1	19	10	5	3	0	18	62
Total	109	35	94	105	343	83	18	52	59	217	86	60	79	73	298	88	39	45	62	234	1092

FIGURE 13 A: Seasonal changes in Total Pitfall Trapped Invertebrates

FIGURE 13 B: Seasonal changes in Numbers of Pitfall Trapped Invertebrates on each Transect



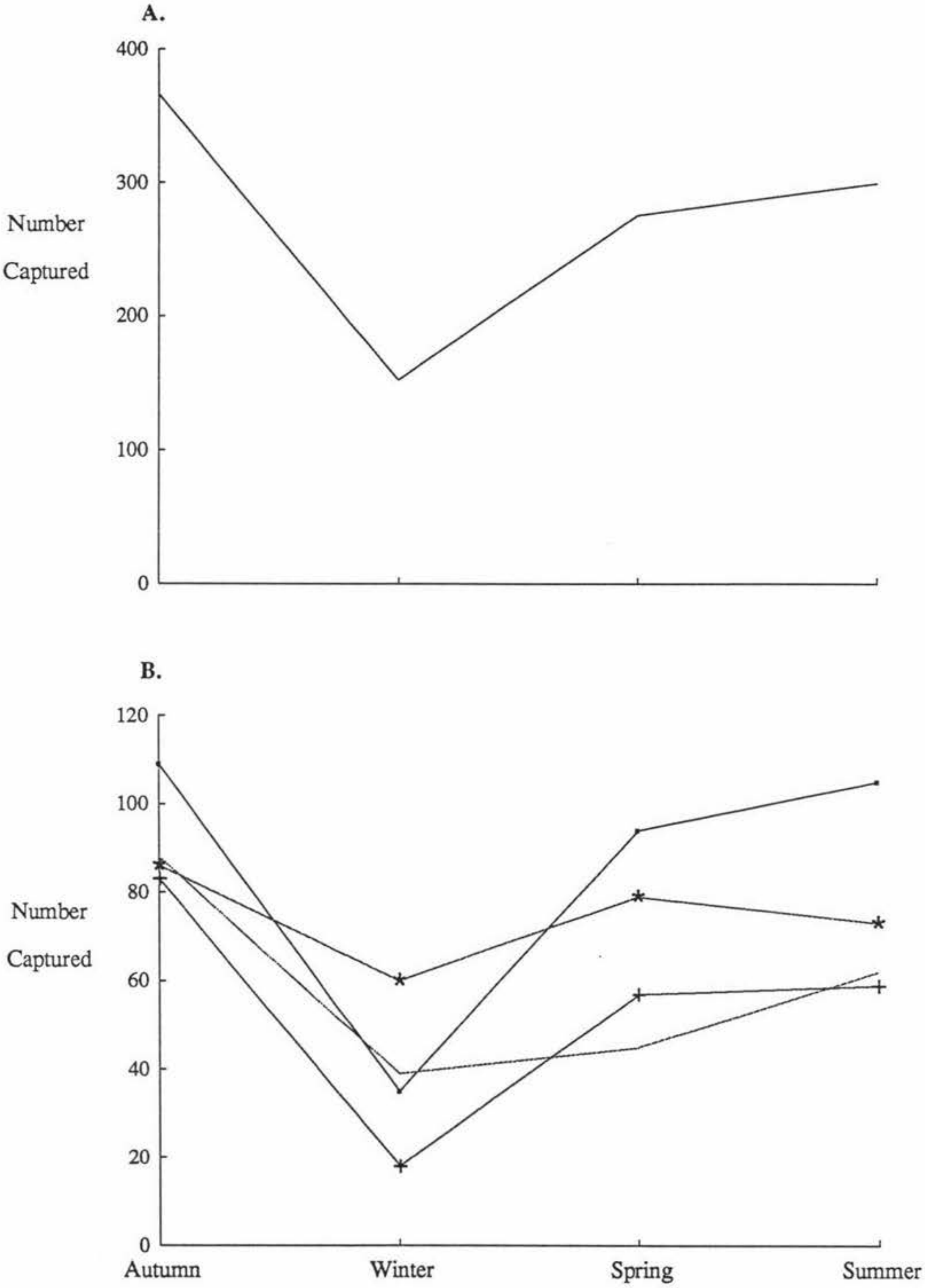
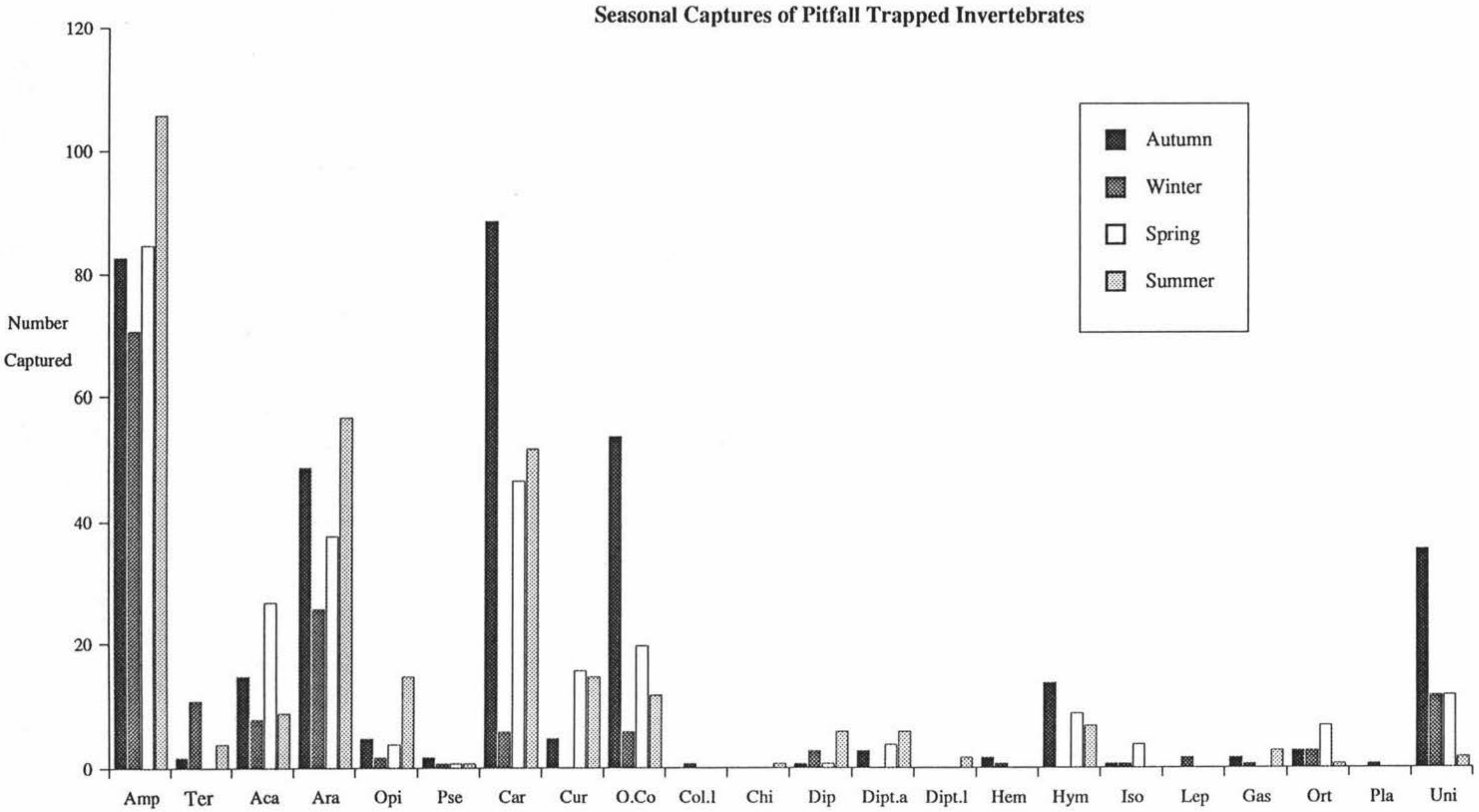

A.
400
300
Number
Captured
200
100
0
B.
120
100
80
Number
Captured
60
40
20
0
Autumn
Winter
Spring
Summer

FIGURE 14: Seasonal Captures of Pitfall Trapped Invertebrates

Amp = Amphipoda
Ter = Terricolae
Aca = Acari
Ara = Araneida
Opi = Opilione
Pse = Pseudoscorpione
Car = Carabidae
Cur = Curculionidae
O.Col = Other Coleoptera
Col.l = Coleoptera larvae
Chi = Chilopoda
Dip = Diplopoda
Dipt.a = Diptera adults
Dipt.l = Diptera larvae
Hem = Hemiptera
Hym = Hymenoptera
Iso = Isopoda
Lep = Lepidoptera
Gas = Gastropoda
Ort = Orthoptera
Pla = Planaria
Uni = Unidentified



Seasonal Captures of Pitfall Trapped Invertebrates

Acari

Mites were caught on all transects being most abundant on B and least common on D (table 16). On transect B most were caught in spring and least in winter. On transect C they were more common in autumn and spring than in winter and summer. On transect D, mites were only caught in spring, and winter and spring trapping caught the greatest number of mites on transect E (table 16).

Araneida

Spiders were common on all transects and were the third most abundant invertebrate overall (table 16). Trapping on transect D yielded the highest number of spiders which were most abundant in summer (table 16). Trapping on transect B caught similar numbers in all seasons (Table 16) while on C, spider numbers peaked in autumn followed by summer and spring and were lowest in winter (table 16). On transect E, highest numbers were caught in autumn and summer followed by winter and then spring.

Opiliones

The greatest number of Opiliones were captured on transect D, where they were most abundant in summer (table 16). On transect B they were caught in low numbers in all seasons, and on C, low numbers were trapped in all seasons except spring (table 16). On transect E, only one Opilione was captured, in spring (table 16).

Pseudoscorpiones

Pseudoscorpiones were only caught on transect B and D. One individual was caught in each of autumn and spring on transect B and one in autumn, winter, and summer on D (table 16).

Crabidae

Carabids were the most common form of beetle captured and they were abundant on all transects, although trapping on B produced by far the greatest number (table 16). Overall captures were highest in autumn (figure 14) and only two carabids were caught in winter, both on transect E (table 16). On transects B and D, carabids were caught mainly in autumn, on C, captures were highest in autumn and spring. On transect E, carabid beetels were caught predominantly in autumn and summer (table 16).

Curculionidae

Weevils were trapped on all transects, C yielding the greatest numbers. Captures were highest in summer and spring on all transects and none were caught in winter (table 16).

Other Coleoptera

Other beetles were trapped on all transets and were most abundant in autumn, especially on transect C (table 16).

Coleoptera Larvae

One beetle larvae was captured on transect B, in winter (table 16).

Chilopoda

Only one centipede was caught on transect E, in summer (table 16).

Diplopoda

Millipedes were only collected in small numbers on transects C, D and E (table 16). Highest total numbers were caught in summer and winter respectively (figure 14).

Diptera adults

Diptera adults were represented only by flies. Low numbers were caught on all transects (figure 16) and mostly in summer (figure 14).

Diptera larvae

Only two individuals were captured on transect B, both in summer (table 16).

Hemiptera

Plant bugs were only caught in very low numbers on transects C and D. They were trapped in autumn and winter on transect C and in autumn on D (table 16).

Hymenoptera

Ants were the only hymenopteran form caught. They occurred mainly on transect D, mostly in autumn, although they were also present in spring and summer (table 16). On transect B, only one ant was collected; in spring, on C they were trapped in spring and summer. On E, they were captured in autumn and spring (table 16). No ants were caught in winter trapping (figure 14).

Isopoda

Two woodlice were caught on each of transects B, C and E with none trapped on D (table 16). They were captured in all seasons except summer (figure 14).

Lepidoptera

Adult moths were the only form of Lepidoptera present in pitfall trapping results and only two were caught; one in winter on transect B and one in winter on E (table 16).

Gastropoda

Gastropoda were only represented by snails. Few were caught on any transect and none occurred in spring (table 16, figure 14).

Orthoptera

Wetas were the only orthopteran form trapped. They were caught only caught on transect D, where they occurred in all seasons but mostly in spring (table 16, figure 14).

Planaria

One flatworm was caught in winter on transect D (table 16).

Unidentified

Unidentified invertebrates were trapped in all seasons on all transects with greatest numbers occurring in autumn (table 16, figure 14).

Diversity

Each transect showed a similar diversity of invertebrates, each being represented by 15 to 17 of the 22 invertebrate types trapped. Combined seasonal tallies indicate that there was only slightly less diversity in spring than in other seasons.

Night Sampling

A total of 708 invertebrates were captured during night sampling. The greatest number were caught on transect B, followed by E, D and C (table 17, p. 63). Capture rate was highest in spring, followed by summer, winter then autumn (figure 15a, p. 64). Results of night invertebrate sampling are presented in table 17 and figures 15a & b and 16 (p. 65).

Amphipoda

Amphipods were the third most abundant invertebrate and highest numbers were caught on transect B (table 17). They were trapped in all seasons on all transects except for in autumn on D (table 17).

Terricolae

Few earthworms were caught; one each on transects C, D and E and only in winter and spring (table 17, figure 16).

Acari

Similarly few mites were trapped and only on transect B, C and D (table 17).

Araneida

Spiders were the most common invertebrate captured in night sampling (table 17). Sampling on transect B yielded the highest numbers followed by E, D and C (table 17). Overall, seasonal capture rates did not vary much, although slightly higher numbers were caught in spring (figure 16). Spiders were abundant in all seasons on transect B and E (table 17). On transect C, numbers were higher in autumn and spring compared to winter and summer (table 17) and on D, numbers were higher in spring and summer than in autumn and winter (table 17).

TABLE 17: Seasonal Captures of Night Sampled Invertebrates

				B					C					D					E			
Invertebrate		A	W	Sp	Su	Tot	A	W	Sp	Su	Tot	A	W	Sp	Su	Tot	A	W	Sp	Su	Tot	Tot
Amphipoda		5	6	12	6	29	3	1	2	2	8	0	10	5	4	19	4	1	5	4	14	70
Terricolae		0	0	0	0	0	0	1	0	0	1	0	1	0	0	1	0	0	1	0	1	3
Acarina		0	1	0	2	3	0	0	1	0	1	0	0	0	1	1	0	0	0	0	0	5
Araneida		23	26	38	27	114	21	9	18	10	58	8	9	23	25	65	26	20	18	21	85	322
Opilione		1	7	2	2	12	7	1	0	0	8	0	0	0	2	2	0	0	0	3	3	25
Blattodea		3	3	8	1	15	0	3	12	5	20	0	5	2	27	34	0	6	9	3	18	87
Chilopoda		0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1
Diplopoda		2	2	1	2	7	0	0	0	0	0	0	1	0	0	1	2	0	1	0	3	11
Coleoptera		1	0	0	5	6	0	0	0	0	0	1	0	0	0	1	2	0	0	2	4	11
Diptera adult		0	0	35	6	41	0	0	0	0	0	0	1	1	2	4	0	0	0	3	3	48
Diptera larvae		0	0	0	0	0	0	0	15	0	15	0	0	0	3	3	0	0	0	0	0	18
Hemiptera		2	0	0	0	2	0	0	0	0	0	0	4	0	0	4	0	3	0	0	3	9
Hymenoptera		0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	2	2	3
Isopoda		0	1	2	0	3	0	0	1	0	1	0	1	0	0	1	0	0	0	0	0	5
Lepidoptera		0	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0	1	3
Gastropoda	(slug)	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	0	0	0	1	1	3
	(snail)	0	1	0	0	1	1	3	0	0	4	0	0	0	0	0	2	0	2	1	5	10
Orthoptera		7	7	1	4	19	0	4	0	11	15	0	1	0	4	5	5	6	9	6	26	65
Phasmatodea		0	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Planaria		3	0	0	1	4	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	5
Unidentified		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Total		48	54	101	57	259	32	23	51	29	135	9	33	52	49	143	41	36	46	48	171	708

FIGURE 15 A: Seasonal changes in Total Numbers of Night Sampled Invertebrates

FIGURE 15 B: Seasonal changes in numbers of Night Sampled Invertebrates on each Transect

-■- Transect B
-+- Transect C
-*- Transect D
— Transect E

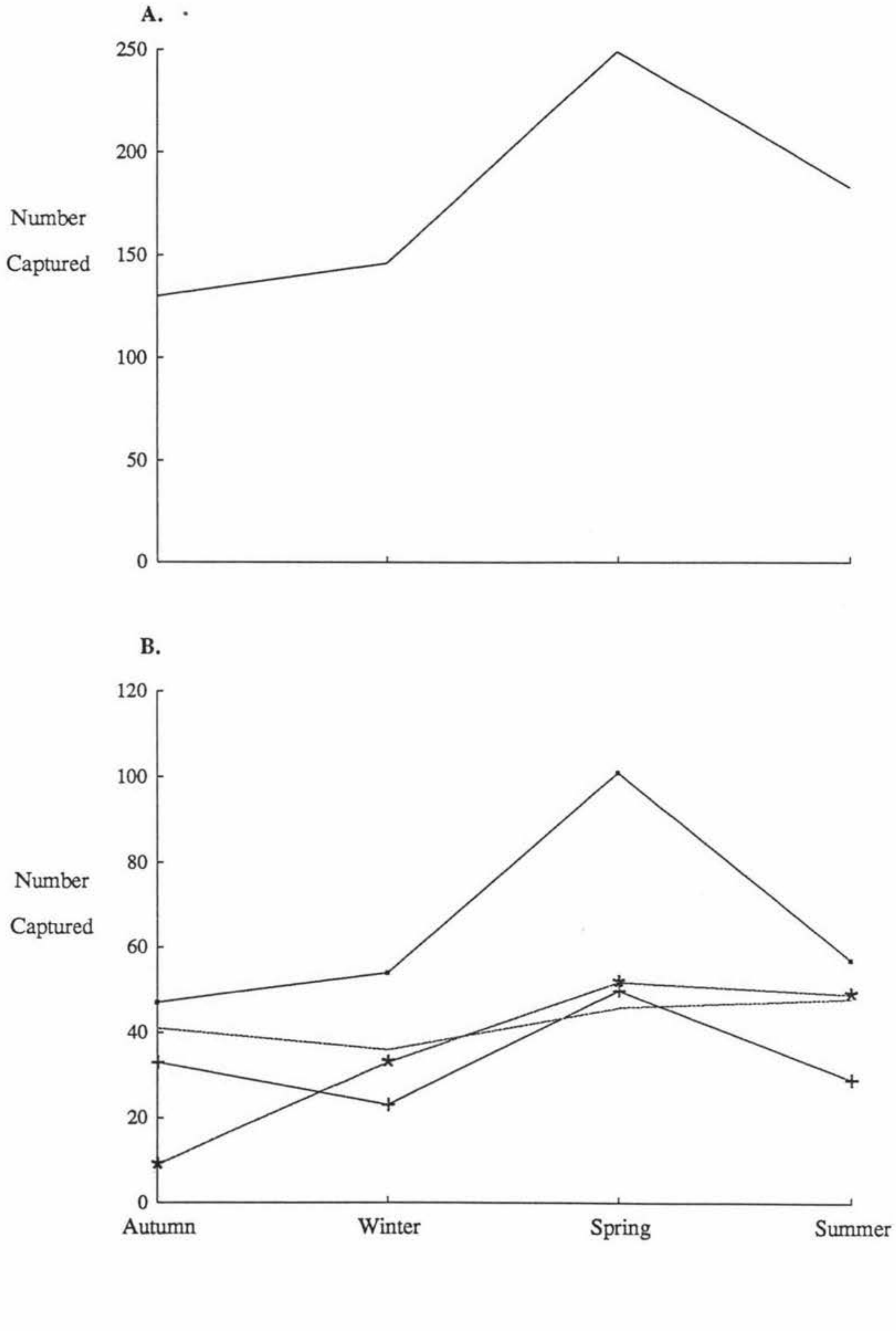
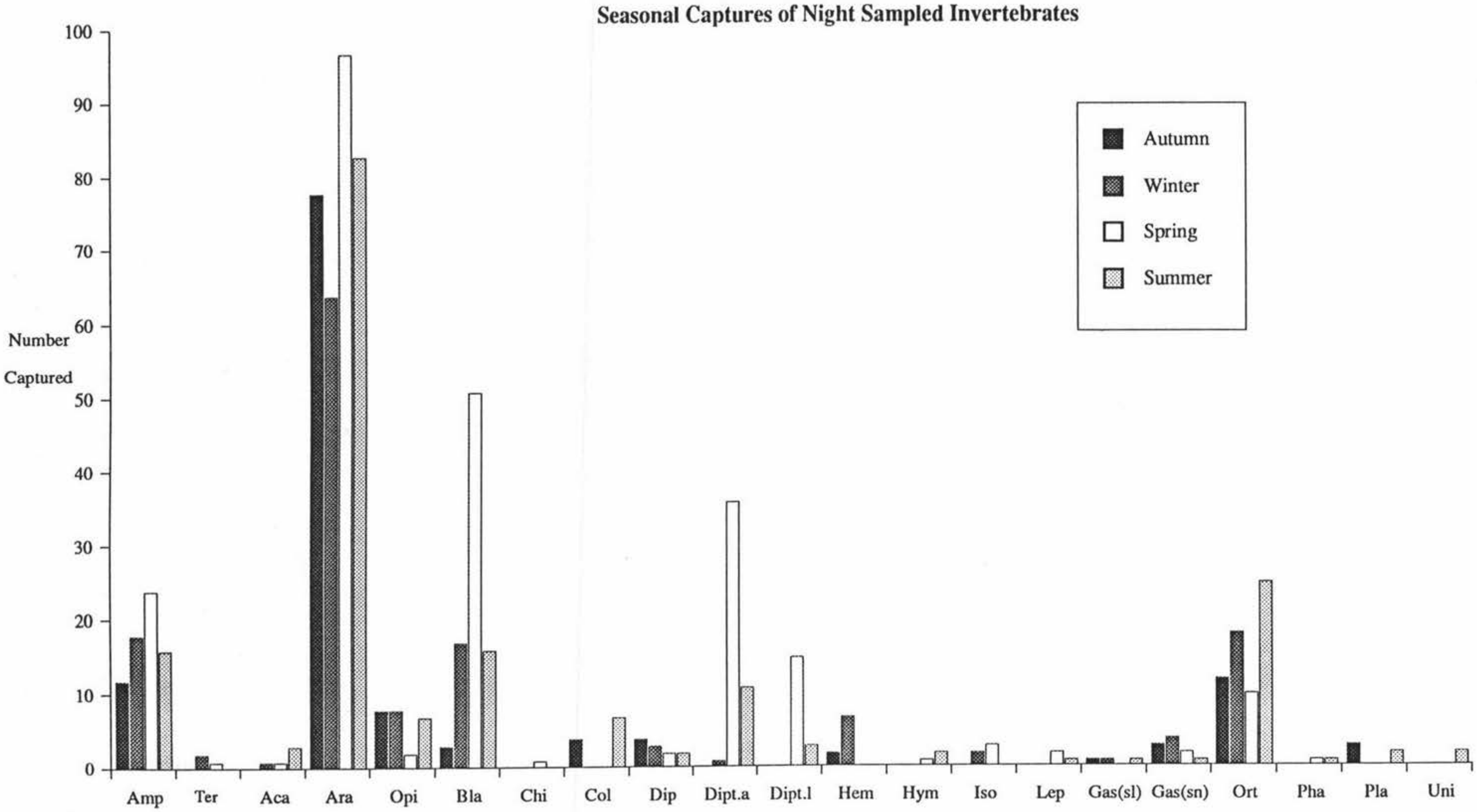

A.
250
200
150
100
50
0
Number
Captured
B.
120
100
80
60
40
20
0
Number
Captured
Autumn
Winter
Spring
Summer

FIGURE 16: Seasonal Captures of Night Sampled Invertebrates

Amp = Amphipoda
Ter = Terricolae
Aca = Acari
Ara = Araneida
Opi = Opilione
Bla = Blattodea
Chi = Chilopoda
Col = Coleoptera
Dip = Diplopoda
Dipt.a = Diptera adults
Dipt.l = Diptera larvae
Hem = Hemiptera
Hym = Hymenoptera
Iso = Isopoda
Lep = Lepidoptera
Gas(sl) = Gastropoda (slug)
Gas(sn) = Gastropoda (snail)
Ort = Orthoptera
Pha = Phasmatodea
Pla = Planaria
Uni = Unidentified


Seasonal Captures of Night Sampled Invertebrates
Number Captured
100
90
80
70
60
50
40
30
20
10
0
Amp
Ter
Aca
Ara
Opi
Bla
Chi
Col
Dip
Dipt.a
Dipt.l
Hem
Hym
Iso
Lep
Gas(sl)
Gas(sn)
Ort
Pha
Pla
Uni
Autumn
Winter
Spring
Summer

Opiliones

Opiliones were most common on transects B and C (table 17) with few captured on transects D and E (table 17). On transect B, most were caught in winter and on C they were only captured in autumn and winter (table 17). On transect D and E Opiliones were only trapped in summer (table 17).

Blattodea

Cockroaches were the second most common invertebrate captured in night sampling. They were most abundant on transect D followed by C, E then B (table 17). Cockroaches were more abundant in spring than in winter and summer, and few were present in autumn (figure 16). This seasonal pattern of abundance occurred on all transects except B where numbers were highest in spring, and least in summer (table 17).

Chilopoda

Only one centipede was caught; on transect C in spring (table 17).

Diplopoda

Most millipedes were caught on transect B, very low numbers occurred on D and E and none on C (table 17). They were trapped in all seasons on transect B, in autumn and spring on E and in winter only on D (figure 17).

Coleoptera

Beetles were caught on all transects except C, and only in autumn and summer. Most were captured on transect B, followed by E then D (table 17). No carabid beetles were trapped in any night sampling session.

Diptera adults

Flies and craneflies were the only dipterans collected. Most were captured on transect B, mainly in spring. Only small numbers occurred on transects D and E and none were caught on C (table 17).

Diptera larvae

Dipteran larvae were captured on two lines and in two seasons only; on transect C in spring and on D in summer (table 17).

Hemiptera

A total of nine plant bugs were captured in night sampling, two were caught on transect B in autumn, four on D in winter and three on E in winter (table 17).

Hymenoptera

As with the pitfall trapping ants were the only hymenopteran form collected. Only one was taken on transect D, and two on E (table 17).

Isopoda

Isopods were caught in small numbers on all transects except E and only in winter and spring (table 17).

Lepidoptera

Adult moths were the only lepidopteran form collected. These were caught on transects B and E in spring, and on C in summer (table 17).

Gastropoda

Slugs

Three native leaf-vein slugs were captured. They only occurred on transects C and E (table 17).

Snails

Most snails were caught on transects C and E, only one on B and none on D (table 17). They were present in all seasons (figure 16).

Orthoptera

Wetas were common on all transects except D. Most were collected on transect E with captures on B the next highest (table 17). In total, wetas were most abundant in summer (figure 16), although on transect B they were more abundant in autumn and winter. On transect E, they were common in all seasons with peak abundance in spring (table 17). On transects C and D, wetas were only present in winter and summer (table 17).

Phasmatodea

Stick insects were only caught on transect B, one in spring and one in summer (table 17).

Planaria

Most flatworms were collected on transect B (table 17), and only in autumn and summer (figure 16).

Unidentified invertebrates

Only two individuals were unidentifiable and these were captured on transect E in summer (table 17).

Invertebrate Sampling Summary

The invertebrate groups captured in pitfall trapping and night sampling were very similar; only a few groups were caught by one method and not the other. Sampling on transect B yielded the greatest number of invertebrates and transect C the least for both methods. Both sampling methods showed that invertebrate numbers were low in winter. Pitfall trapping yielded highest numbers in autumn whereas night sampling produced lowest numbers in autumn.

Only a few groups were common in either sampling method. For pitfall trapping the most abundant invertebrates were amphipods, carabid beetles, spiders and other beetle families; for night sampling the most abundant were spiders, cockroaches, amphipods and wetas. Both sampling methods indicated that these groups were present all year round, although most showed strong seasonal fluctuations in abundance. They were all least abundant in winter except for amphipods and wetas which were least common in autumn and spring respectively in the night sampling.

Features that were characteristic of pitfall trapping were the high numbers of amphipods (32% of all captures) and high numbers of carabid beetles and spiders. These groups together made up 65% of all pitfall captures. Wetas were only caught on transect D. Ants were also mainly caught on transect D.

Features of the night sampling include the large number of spiders (46% of all night sampled invertebrates) and a high number of wetas and cockroaches compared with the pitfall trapping. Few wetas were caught on transect D. A disproportionate number of the Diptera adults were trapped on B and larvae on C. No carabid beetles and few other beetles were captured in the night sampling.

Identification of Invertebrates

Only two types of weta were caught in the invertebrate sampling. These were cave wetas (Rhaphidophoridae) and ground wetas (Stenopelmatidae). They were identified by G.W. Ramsay, Entomology Division D.S.I.R., Auckland, as:
(1) Stenopelmatidae: *Zealandosandrus* spp. possibly fiordensis and
(2) Rhaphidophoridae: *Isoplectron* spp.
No tree wetas (*Hemideina*) were caught on Stewart Island.

Two species of carabidae, *Holcaspis stewartensis* Butches, 1984 and *Mecodema infimate* Lewis, 1902, and one species of Scarabidae, *Sericospilus eximia* Brown, 1917, were identified by R. Craw, Entomology Division D.S.I.R., Auckland.

3.7.2 Phenology

To simplify interpretation phenological results have been summarized in the figures 17.1 - 17.23 (p. 70-77), similar to Leathwick (1984).

Key To Figures 17.1-17.23

(1) Vegetative growth: The presence of leaf buds is represented by a dashed line, expanding leaf buds by a solid line and new leaves by a dotted line.

(2) Flowers: The presence of flower buds and/or expanding flower buds are represented by a dashed line, duration of flowers by a solid line and petal fall by a dotted line.

(3) Fruit: The dashed line represents unripe fruit, solid line ripe fruit and dotted line seed fall.

The large dot (•) indicates the peak period of occurrence, where obvious, for each class.

Phenology summary

Vegetative growth

Most species had vegetative growth in almost all seasons but variation between species and within species on different transects was great. New leaves were abundant.

Flowers

Very little flowering was recorded. Flowers and petal fall were noted on 14 of the 23 species and of these, flowering occurred in spring and summer for all except *Leptospermum scoparium* and *Weinmannia racemosa*. A few species had some flowering development in autumn and winter.

Fruit

There was no prolific fruiting or seed fall from any species in 1986. Great variation was found in the seasonal fruiting patterns between species and often within species on different transects. Overall, ripe fruit and seedfall was most common in autumn and winter. Some species produced ripe fruit and/or seed fall all year round.

FIGURE 17: Phenology

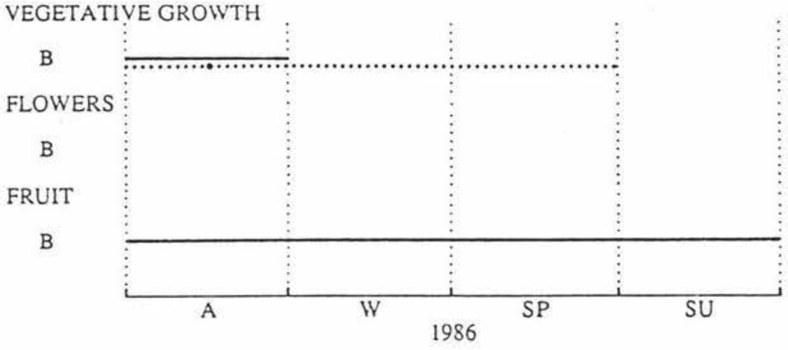
17.1 ***Blechnum discolor*** - Vegetative growth mainly occurred in the early part of the year with a peak in the occurrence of new leaves in autumn, although they were present through to spring. Mature reproductive fronds were present in each season.

17.2 ***Coprosma colensoi*** - Leaf buds appeared in spring and summer with peak expansion in summer. New leaves were present all year round. Unripe fruit was present in autumn and summer while ripe fruit occurred from autumn through to spring and seed fall was only recorded in winter.

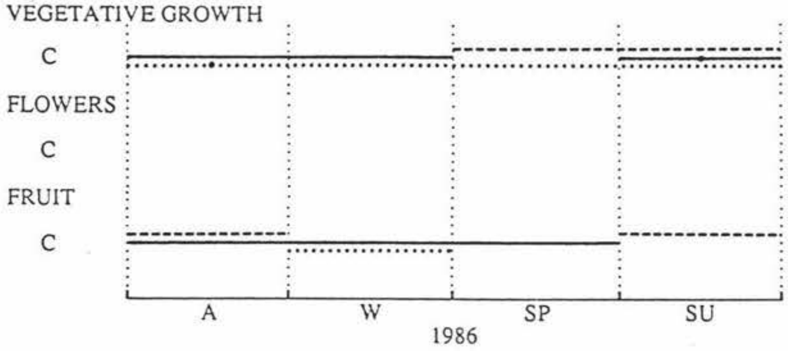
17.3 ***Coprosma foetidissima*** - The pattern of vegetative growth was generally similar on each transect with peak leaf bud occurrence in spring and expansion starting in spring and peaking in summer. New leaves were present in each season and flowers were only recorded on transect E in summer. Occurrence of unripe and ripe fruit also peaked in autumn on transect B, although they were also present in winter and summer and seedfall was only recorded in spring. On transect E, unripe and ripe fruit occurred in autumn and summer and seedfall was recorded in autumn.

FIGURE 17: Phenology

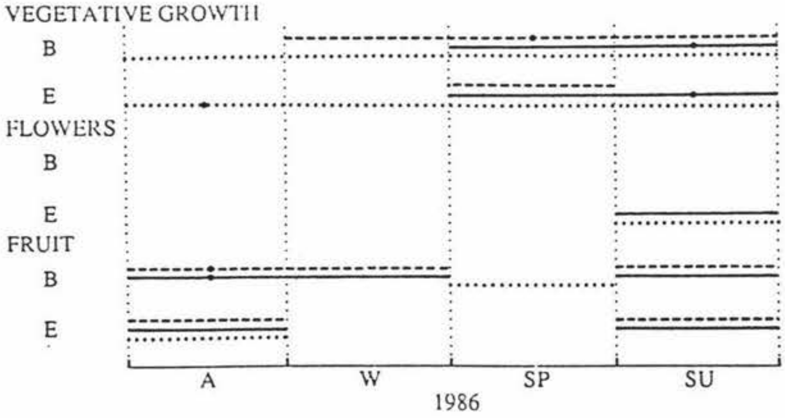
17.1 *Blechnum discolor*



17.2 *Coprosma colensoi*



17.3 *Coprosma foetidissima*

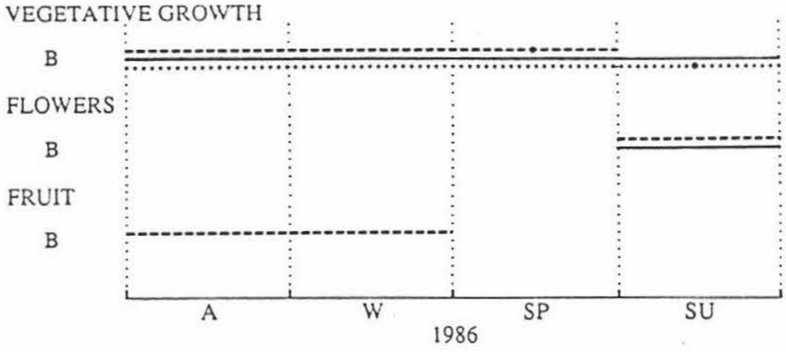


17.4 ***Coprosma lucida*** - Leaf buds occurred from autumn through to a peak in spring with expansion occurring all year round. New leaves were also present in all seasons, although there was a peak in their occurrence in summer. Flowering only occurred in summer and a small amount of unripe fruit was noted in autumn and winter.

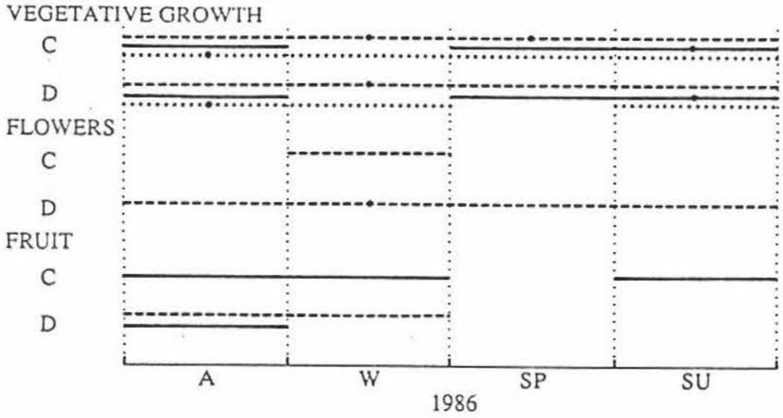
17.5 ***Cyathodes empetrifolia*** - Similar patterns of vegetative growth were recorded on both transects. Leaf buds were present all year round but peaked in winter on transect D and in winter and summer on C. Expanding leaf buds were present in all seasons except winter with peak occurrence in summer. Occurrence of new leaves peaked in autumn on both transects and they were present in all seasons on C, and in all seasons but spring on D. Flower buds peaked in occurrence in winter on both transects and no flowers were noted. On transect C, ripe fruit was recorded in all seasons except summer. On D, unripe fruit was present in autumn and winter and ripe fruit only occurred in autumn.

17.6 ***Cyathodes juniperina*** - Leaf buds were present in all seasons on transect B but were absent in summer on C, D, and E. Peak occurrence was in spring on all transects, although on B, the peak occurred earlier in winter and extended into spring. Expanding leaf buds were present in summer on all transects and also in autumn and winter on B and C, and in autumn on D. New leaves were present in all seasons on transect E and in all seasons but summer on B, C and D. Flower buds were present in autumn, winter and spring on B, C and E, and in all seasons on D. Subsequent flowering and petal fall occurred in summer on all transects, although flowering also occurred earlier in spring on B. Ripe fruit and seed fall occurred all year round on each transect except B, where seed fall only occurred in winter and spring.

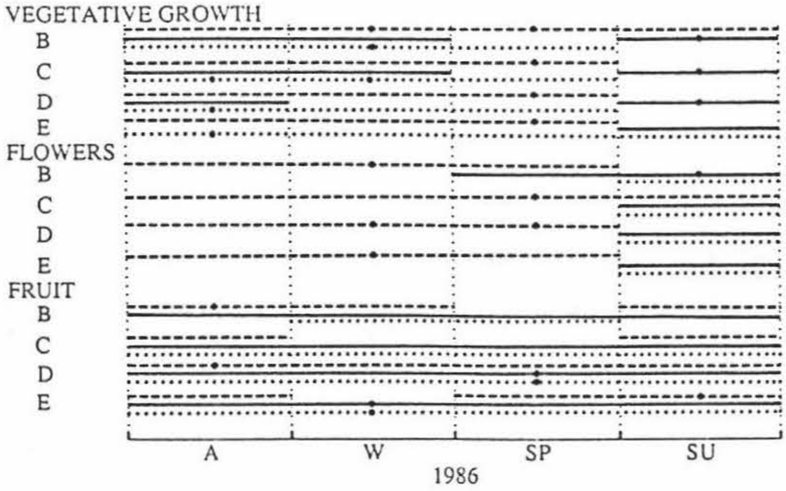
17.4 *Coprosma lucida*



17.5 *Cyathodes empetrifolia*



17.6 *Cyathodes juniperina*

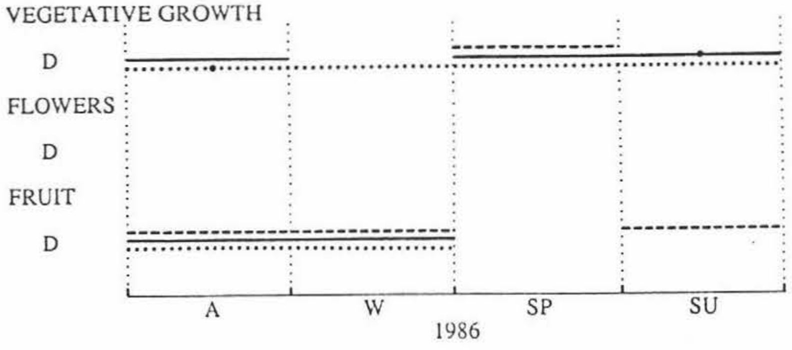


17.7 ***Dacrydium cupressinum*** - Leaf buds were only recorded in spring with peak expansion later in summer. New Leaves were present all year round with peak occurrence in autumn. No cones were recorded and fruit and seed fall occurred in autumn and winter, although unripe fruit was also present in summer.

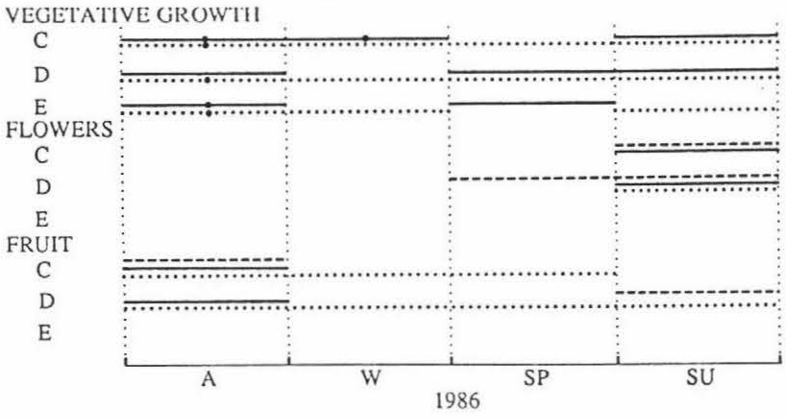
17.8 ***Dracophyllum longifolium*** - The seasonal occurrence of expanding leaf buds varied on each transect. On C, peaks in abundance occurred in autumn and winter, although they were also present in summer. On D, leaf buds were present in autumn, spring and summer but no obvious peak was recorded. On transect E, expanding leaf buds were present in spring and autumn with peak occurrence in autumn. New leaves were present all year round on transect C and D but they were absent in spring on E. Flowering occurred in spring and summer on transect C and D and flower buds were also present in spring on D. The presence of seed pods also varied between transects. Unripe pods, ripe pods and seedfall occurred in autumn on transect C with seed fall extending through to spring. On D, unripe pods were only present in summer and ripe pods only in autumn, although seed fall continued all year round. No pods were recorded on transect E.

17.9 ***Gahnia procera*** - Vegetative growth occurred in all seasons with peaks in leaf bud expansion in autumn on transects C, D and E and in winter on B. Mature seed stalks were found only on transects B, C and D. On transect B, seed fall was recorded in autumn while on C, ripe seed stalks were found in autumn and winter. On transect D, ripe seed stalks were recorded in autumn, winter and spring. Seed fall occurred in all seasons on transects C and D.

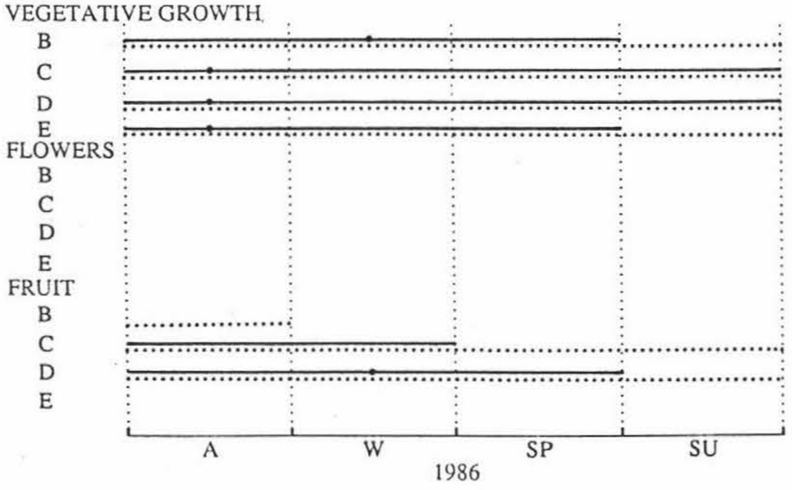
17.7 ***Dacrydium cupressinum***



17.8 ***Dracophyllum longifolium***



17.9 ***Gahnia procera***

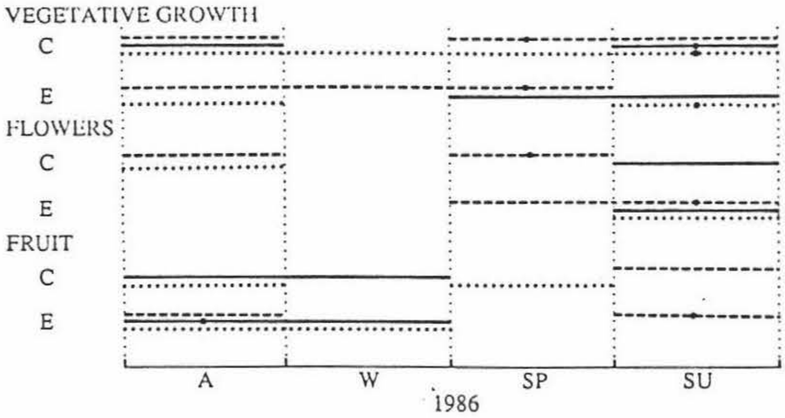


17.10 ***Gaultheria antipoda*** - Leaf buds were present in autumn, spring and summer on transect C and from autumn through to spring on E with peak occurrence in spring on both transects. Occurrence of expanding leaf buds peaked in summer on transect C and they occurred in spring and summer on E. New leaves were present all year round on C, but on E, they were only recorded in autumn and summer, although peaks in their occurrence were in summer on both transects. Flowers were present in summer, on transect C, following the peak in flower bud occurrence in spring. Petalfall occurred in autumn. On E, occurrence of flower buds peaked later in summer and petalfall was also recorded in this season. Similar patterns of fruiting occurred on both transects. Unripe fruit peaked in occurrence in summer, ripe fruit occurred in autumn and winter and seedfall occurred in autumn and spring on C and in autumn and winter on E.

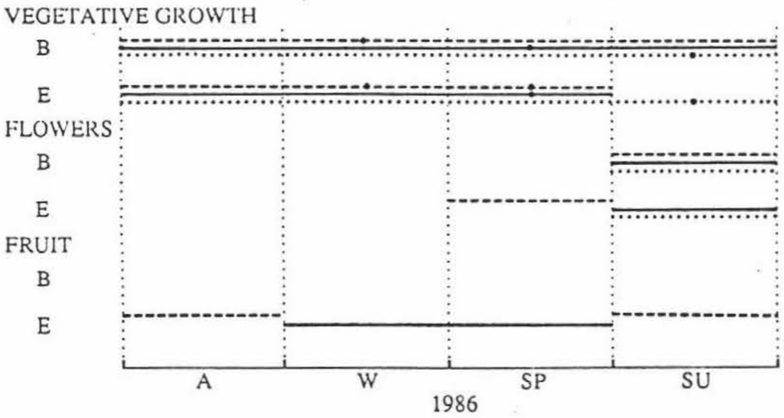
17.11 ***Griselinea littoralis*** - Peaks in the presence of leaf buds occurred in winter on transect B and in both winter and spring on E. Expansion of leaf buds occurred all year round on B and in all seasons but summer on E, with peak expansion in spring on both transects. Flowers only occurred in spring and summer on both transects, although flower buds were present in spring on E. No fruit was recorded on B but on E, small amounts of unripe fruit were present in autumn and summer, while ripe fruit was present in winter and spring.

17.12 ***Halocarpus biformis*** - Leaf buds were present in autumn, spring and summer with peak expansion in summer. New leaves were present in all seasons except spring. Young pollen cones appeared in winter and dehisced pollen cones were recorded in summer. No unripe or ripe fruit was recorded but very small amounts of seed fall were noted in autumn and winter.

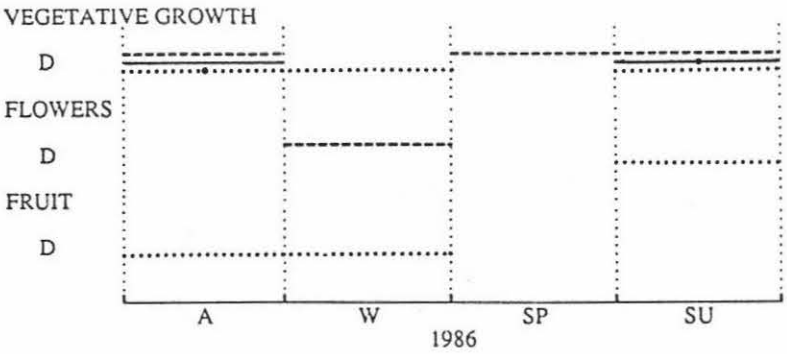
17.10 *Gaultheria antipoda*



17.11 *Griselinia littoralis*



17.12 *Halocarpus biformis*

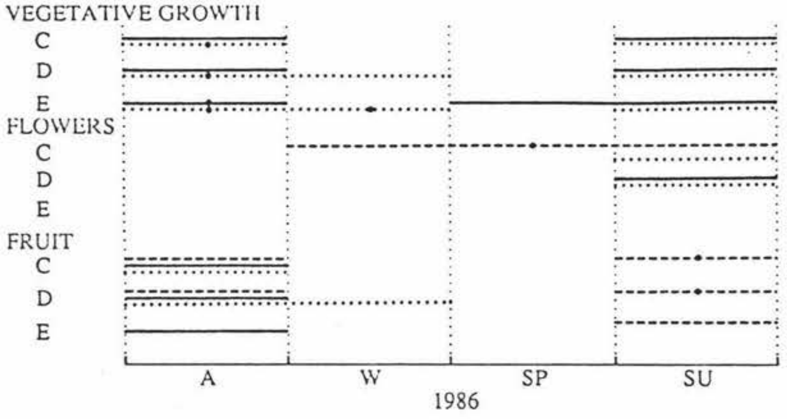


17.13 ***Lepidothamnus intermedius*** - Similar patterns of vegetative growth occurred on all transects with expansion of leaf buds and new leaves predominantly occurring in autumn and summer. Pollen cones were only recorded on transects C and D. Immature cones were found only on transect C, in winter, spring and summer with peak occurrence in spring. Ripe cones were recorded on transect D in summer while dehisced pollen cones were recorded in summer on both C and D. No pollen cones were recorded on transect E. Unripe fruit occurred in summer on all three transects but was also present in autumn on C and D. Ripe fruit was present in autumn on all three transects and seedfall occurred in autumn on C and D but also extended into winter on D.

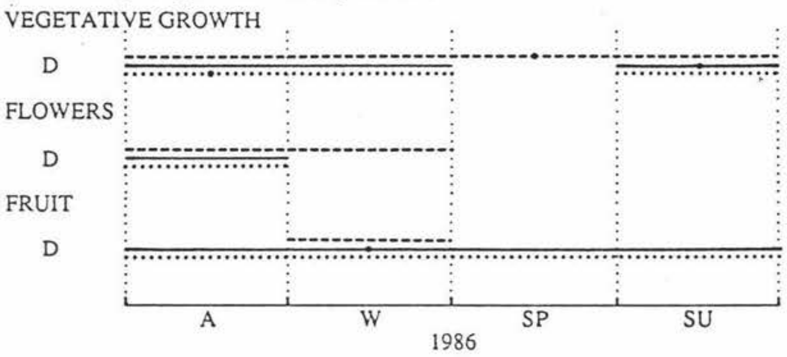
17.14 ***Leptospermum scoparium*** - Vegetative growth occurred in each season with peak leaf bud occurrence in spring and subsequent leaf bud expansion predominating in summer. Peak occurrence of new leaves was in autumn. All flowering occurred in autumn, although flower buds were also present in winter. Unripe pods occurred in winter, whereas ripe pods and seed fall occurred all year round, although peak occurrence of pods was in winter.

17.15 ***Luzuriaga parviflora*** - Expanding leaf buds and new leaves occurred in autumn and summer on transect C. On E, leaf buds occurred in spring, expansion followed in summer and new leaves occurred in all seasons except winter. Unripe and ripe fruit was present in each season on transect C, but seed fall was only recorded in autumn. On E, the presence of fruit was confined to autumn and winter.

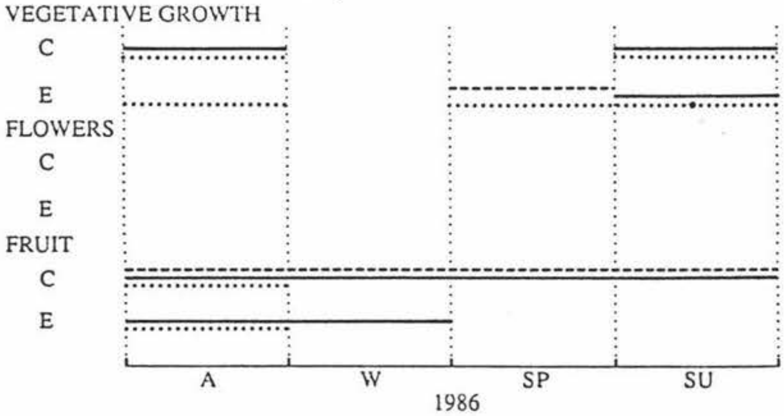
17.13 *Lepidothamnus intermedium*



17.14 *Leptospermum scoparium*



17.15 *Luzuriaga parviflora*

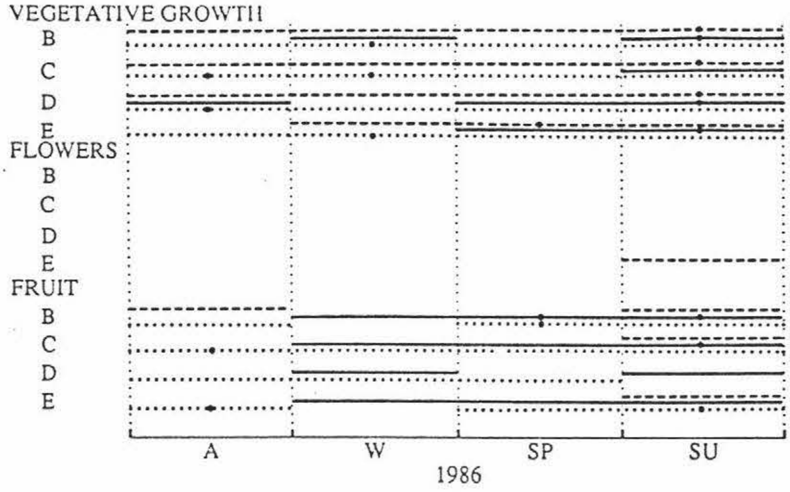


17.16 ***Metrosideros umbellata*** - Leaf buds occurred in each season on all transects except for in autumn on E. Peak occurrence was in summer on B, C, and D, and in spring on E. Leaf bud expansion peaked in summer and new leaves were present all year round on all transects. No flowering was recorded but flower buds were present in summer on transect E. Unripe capsules were recorded in summer on C and E and in both summer and autumn on B. Similar occurrences of ripe capsules were found on all transects, although on D none were recorded in spring. Seedfall occurred in autumn, spring and summer on transects B and E, in autumn, winter and spring on D and in all seasons on transect C.

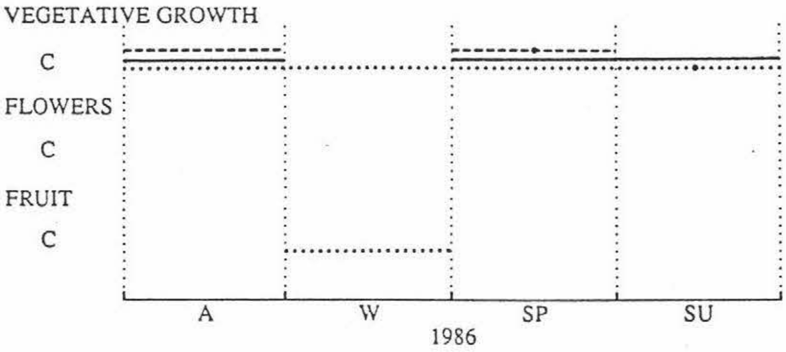
17.17 ***Myrsine divaricata*** - Leaf buds were present only in autumn and spring and expansion occurred in spring, summer and autumn. Little fruit was recorded and only in winter.

17.18 ***Neomyrtus pedunculata*** - Vegetative growth was concentrated in spring and summer, although some new leaves were present in all seasons. No flowering was noted and unripe fruit was only recorded in autumn.

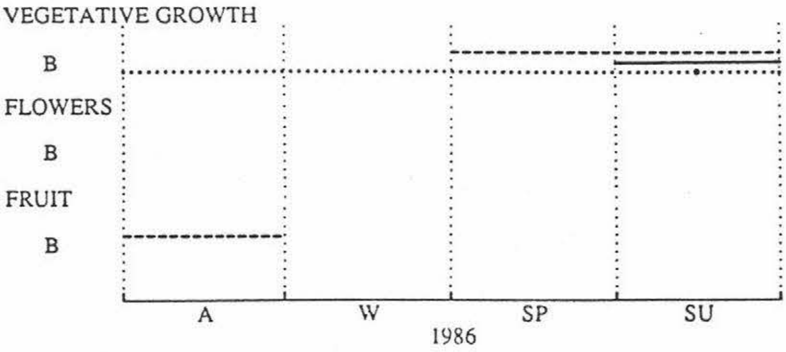
17.16 *Metrosideros umbellata*



17.17 *Myrsine divaricata*



17.18 *Neomyrtus pedunculata*

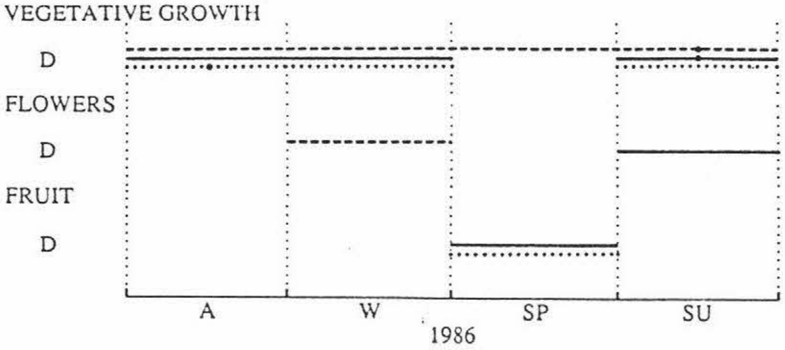


17.19 ***Pentachondra pumila*** - Leaf buds were present all year with peak occurrence in summer. Small amounts of expanding leaf were present in autumn, winter and summer and occurrence of new leaves peaked in autumn. Very few flowers were noted and only in summer while fruit and seed fall was only recorded in spring.

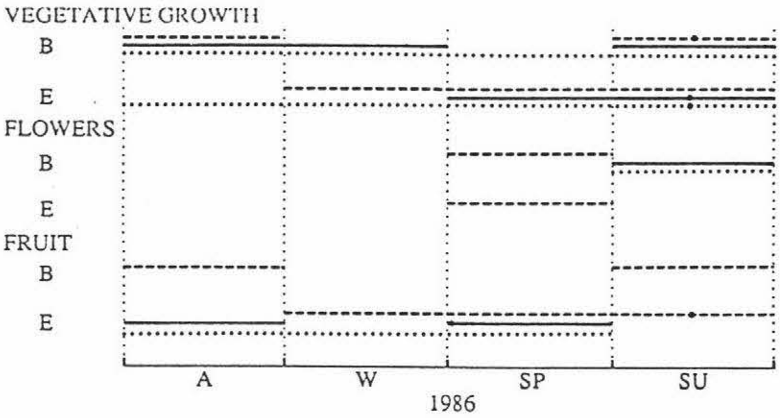
17.20 ***Prumnopitys ferruginea*** - On transect B, leaf buds were present in autumn and summer but expanding leaf buds occurred in all seasons except spring. New leaves occurred all year round. On E, leaf buds were present for longer but the period of expansion was confined to spring and summer; again new leaves were present all year round. Immature cones were present on both transects in spring and ripe and dehisced cones were present in summer on transect B. Only unripe fruit was recorded on transect B, in autumn and summer, but on E, the period of unripe fruit occurrence extended from winter through to a peak in summer. Ripe fruit was recorded in autumn and spring while seed fall occurred from autumn through to spring.

17.21 ***Pseudopanax simplex*** - Slightly different patterns of vegetative growth occurred on each transect. On B, leaf buds were present in autumn and spring and expansion occurred in summer. New leaf was present all year round with peak occurrence in summer. On E, leaf buds were present from autumn through to spring with subsequent expansion in spring and summer, although expanding leaf buds were also present in autumn. New leaves occurred in each season with peak abundance in summer. Only a small amount of petal fall was noted in spring on transect B. Small amounts of unripe fruit were present in all seasons on transect B but no ripe fruit or seed fall were recorded. On E, unripe fruit was present in autumn, spring and peaked in summer and ripe fruit was present in spring and summer.

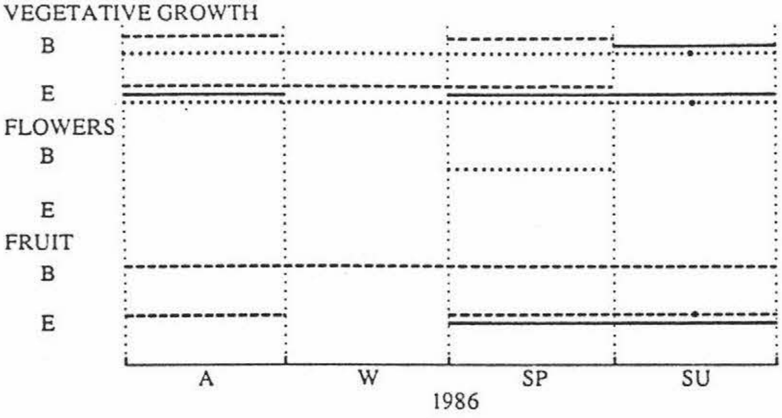
17.19 ***Pentachondra pumila***



17.20 ***Prumnopitys ferruginea***



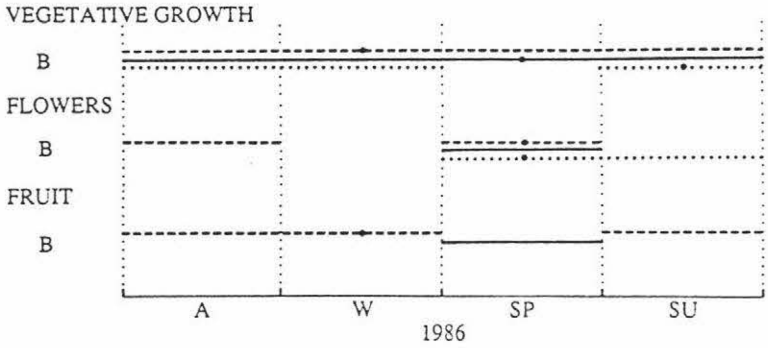
17.21 ***Pseudopanax simplex***



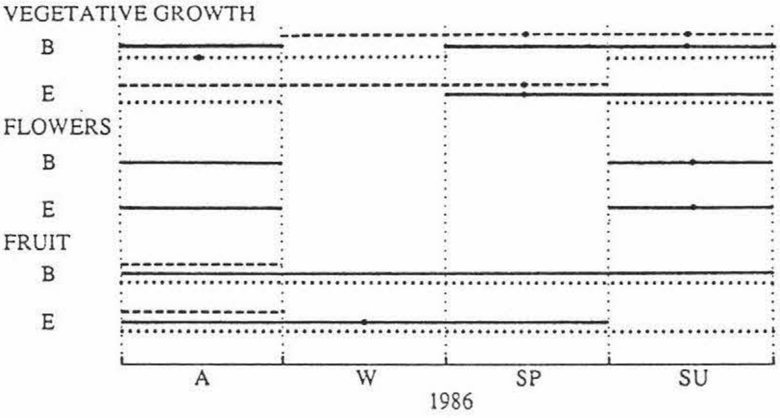
17.22 ***Pseudowintera colorata*** - Vegetative growth occurred all year round, although no new leaves were recorded in spring. Peak flower activity was in spring, although flower buds were present in autumn and petal fall extended into summer. Unripe fruit occurred in all seasons except spring which was the only season in which ripe fruit was recorded.

17.23 ***Weinmannia racemosa*** - On transect B, leaf buds occurred in winter, spring and summer with peak occurrence in spring and summer, while on E, leaf buds were present from autumn through to a peak in spring. Subsequent leaf bud expansion peaked in summer on B and earlier in spring on E. New leaves were present in autumn, winter and summer on B but only in winter and summer on E. Flowering patterns were the same on both transects with peak occurrence of flowers in summer. New pods or racems occurred in autumn on both transects and ripe pods were present in all seasons on B and in all seasons except summer on E. Seedfall occurred all year round on both transects.

17.22 *Pseudowintera colorata*



17.23 *Weinmannia racemosa*



4
Discussion

4.1 Trapping

The Department of Conservation's interest in rats on Stewart Island stems from the relationship between rats, cats and kakapo in the Robertson River region. Predation by feral cats is the greatest threat to the survival of kakapo in southern Stewart Island (Best 1982). However, rats are the staple diet of cats (Karl and Best 1982) and by implication rats will be a major factor in determining the numbers and distribution of cats. Any attempts at reducing cat numbers must therefore take into consideration this predator-prey relationship. By obtaining an index of abundance of rats in areas occupied by kakapo and recording seasonal variation in this abundance, an inference of areas and seasons in which cat abundance is likely to be greatest can be made (D. Cunningham pers comm.). In light of such problems as isolation and inaccessibility of the study area and time constraints of each trip, snap-trapping on index lines was the most practical method of obtaining measurements of rat abundance. This form of trapping was also the most efficient way of collecting rats for autopsy, allowing simple collection of basic measurements on morphology and reproduction. Snap-trapping also permitted the collection of stomachs for later diet analysis. Confined by the above constraints and the obvious necessity to keep methods standard, snap trapping along the same index lines was the most suitable method to continue a final years sampling for myself.

The major advantages of snap-trapping on index lines are the efficiency of operation and the ability to easily compare results from different trapping sessions, for example between seasons, therefore gaining relative measures of changes in population dynamics. There are, however, several problems and assumptions associated with trapping small mammals (Flowerdew 1976). Jensen (1975) and Gurnell (1978) discuss the differential trappability between functional groups within a population, and Stewart (1979), Gurnell (1982) and Dick (1985) discuss the differential trappability between species. McCartney (1970) suggests the two-dimensionality of trapping on the ground may bias population estimates when arboreal species are involved. The many, often incorrect assumptions that must be made when trapping is used for estimating density, are discussed by Pelikan (1969), Ryszkowski (1969), Smith *et al.* (1969), Tamarin and Malecha (1971), Nelson and Clark (1973), Flowerdew (1976) and Stewart (1979). Stickel (1948) criticizes the use of index traplines for estimating populations but Hansson (1967) and Peticrew and Sadlier (1970) advocate their use in certain situations. It must be emphasized that because the area sampled by traplines is unknown, the measure obtained (number of rats/100 trap nights) is an index of abundance or trap success and not an estimate of absolute density. For this reason, I have avoided use of the term density, yet in discussing the work of others I am obliged to refer to the word "density" as they have implied it. However, the calculated index of abundance is probably influenced by density.

When directly comparing the capture rates of trapping between more than one species one must assume that all species have a similar behaviour towards traps and therefore have the same chance of being caught. In the case of ship rats, kiore, and Norway rats this may not be the case. Norway rats are 'notorious neophobics' (Innes 1977), and Dick (1985) suggested trapshyness of Norway rats compared to kiore was indicated by the respective body positions of captured individuals in snap-traps on Kapiti Island. Norway rats were usually just caught by the head or snout whereas kiore were generally well caught with the body positioned over the trap. This suggested the index of Norway rat abundance may have been an under estimation relative to kiore abundance. My trapping supported this theory as similar body positions to those found by Dick (1985) were noted for kiore and Norway rats (plate 6 and 7, p. 80). The body positions of captured ship rats (plate 8, p. 81) were similar to those of Norway rats suggesting that ship rats may be more trap shy than kiore yet similar in trap shyness to Norway rats. Therefore in this study Norway rat and ship rat abundance may be an under estimation relative to kiore abundance. Similar trappability for ship rats and Norway rats on Stewart island was reported by Hickson *et al.* (1986).

The two-dimensionality of trapping on the ground may result in a portion of the population remaining unsampled when arboreal or partly arboreal species are involved (McCartney 1970). In a live trapping study of ship rats in the Orongorongo Valley, New Zealand, Daniel (1972) compared tree trapping and ground trapping results and concluded that traps on the ground were adequately sampling the population. There was not a portion of the population living exclusively in the canopy. However, the presence of more than one species may complicate the situation on Stewart Island. McCartney (1970) suggested ship rats may compete for nest sites with kiore and possibly exclude kiore from the trees. The presence of the predominantly ground dwelling Norway rat may further complicate the situation on Stewart Island. Barnett and Spencer (1951) showed that in an enclosed situation Norway rats may exclude ship rats from nest sites and ship rats predominantly stayed above ground in the presence of Norway rats. Therefore, the possibility exists for a permanent arboreal population of either ship rats or kiore which was not being sampled. This would result in underestimation of their respective abundance. Moors and Cunningham (Department of Conservation) did conduct limited tree trapping on transect B, separate from the index line, on two trips. Only ship rats were captured but the capture rate was so low and the practice so labour intensive that it was impractical for one person to operate both tree trapping and index lines. Therefore tree trapping was discontinued (D. Cunningham pers comm.). This low return suggests either there was no permanent arboreal portion of the rat population on transect B or that rats react differently to traps in the trees and were avoiding them. Intense tree trapping coupled with behavioural studies would gather more useful information into the complexities of arboreal coexistence. The limitations associated with the two-dimensionality of the trapping programme when used to sample animals that occupy three-dimensional space remain. Nocturnal counts have limited success (Dick 1985) and were not practical in this study.

PLATE 6: Kiore

PLATE 7: Norway rat


Supreme

PLATE 8: Ship rat

4.2 Abundance

The overall low index of abundance of 4 rats/100 trap nights on Stewart Island in this study compares with similar low trap success recorded in other New Zealand studies of rats in mainland forests and on large offshore islands (Daniel 1978). Innes (1977) captured 3.89 rats/100 trap nights in a snap trapping study of ship rats in the Tiritea Reserve, Daniel (1972) snap trapped 2.13 ship rats/100 trap nights in the Orongorongo valley and less than five ship rats/100 trap nights were trapped by Fitzgerald and Karl (1979) also in the Orongorongo Valley. Higher capture rates have been recorded from mainland forests including the maximum crude index of 22 ship rats/100 trap nights in Pouakani forest (Beveridge 1964), between 13.2-15.8 ship rats/100 trap nights in South Island forests (Best 1968) and the crude index of 11.5 ship rats/100 trap nights in a *Pinus radiata* plantation in the North Island (Clout 1980). The highest index for a single trapping session in this study was 13.4 rats/100 trap nights in winter 1985. Higher trapping success of rats has also been recorded previously from Stewart Island (Choate and Gibbs 1964, Taylor 1975, Gales 1980 in Hickson *et al.* 1986, Hickson *et al.* 1986), although live trapping at Halfmoon Bay (Hickson *et al.* 1986) demonstrated comparable density estimates to those of Daniel (1972) in the Orongorongo Valley.

Higher abundance of kiore and Norway rats have been found in many island situations (Beveridge and Daniel 1965, Daniel 1969, 1978, Bettesworth 1972a, Dick 1985, Moors 1985, Moller and Craig 1987). Dick (1985) recorded an overall trap success of 15.06 rats/100 trap nights for kiore and Norway rats on Kapiti Island and trapping success of Norway rats from the New Zealand region indicates a range of 0.1 - 37.3 rats/100 trap nights (Moors 1985, Moller and Tilley 1986). Only Moller and Tilley (1986) and this study show overall trap success of Norway rats below 9 rats/100 trap nights (Moors 1985). Therefore the overall low success of trapping on Stewart Island in this study contrasts the generally high trapping success from these other island studies.

A similar pattern of seasonal fluctuations in index of abundance was recorded in each year of trapping. Seasonal changes in abundance are common to most rodent studies in New Zealand (Beveridge 1964, Beveridge and Daniel 1965, Best 1968, Bettesworth 1972a, Innes 1977, Dick 1985, Moller and Craig 1987). Greatest return for trapping effort was in winter of each year which parallels the findings of Best (1968) and Innes (1977). Lowest returns for trapping effort were recorded in autumn or summer of each year. Concurrent fluctuations in food supply have generally been inferred as the major determinant of rodent abundance in New Zealand (Daniel 1978, Craig 1986, Moller and Craig 1987).

Variations in rodent abundance both seasonally and between areas, are caused by several factors which alter rates of reproduction, mortality and movement. Factors considered important include inter- and intra-specific competition (Stoecker 1972, Twimbell 1973, Turner *et al.* 1975, Davis 1979, Heske *et al.* 1984, Brown and Munger 1985), weather and climate (Delany 1974, Moors 1985), latitude (Moller and Craig 1987), food availability both quantitatively and qualitatively (Hansson 1971, Brown and Munger 1985, Moors 1985), habitat structure, including cover, nest sites and shelter (Barnett 1963, Southern 1964, Morris 1984, Dueser and Porter 1986), disease (Barnett 1963), dispersal (Moller and Craig 1987) and predation (Andersson and Erlinge 1977). These factors do not necessarily act independently of each other. For example Rosenzweig (1973) showed that greater densities of heteromyid rodents were found in areas with greatest cover implying habitat structure was a determinant of density, although it was suggested this preference for cover may be a response towards reducing predation.

Moller and Craig (1987) suggest latitude, dispersal, predators and other rodent competitors may all, in part or whole, determine kiore density in New Zealand. They state "..islands with other rodents present tend to have lower kiore density, but these same islands also tend to have predators present, are larger and are situated further south in New Zealand." Large island or habitat size may affect rat density by allowing greater dispersal. Thus lower densities are maintained. Dispersal may also affect seasonal fluctuations in abundance. Only when general rat abundance was highest were ship rats trapped on transect D, and kiore trapped on transect B. The occurrences of these species on these transects where they usually do not occur may be the result of dispersal during periods of high abundance. This would have the effect of reducing the numbers at their point of origin and therefore the seasonal decline in recorded abundance might be initiated.

Interspecific interactions between the three rat species may also limit population levels. In Britain Norway rats have been held responsible for reducing ship rat numbers (Southern 1964). Meeson (1884), White (1887), Watson (1956) and Williams (1973) implicate Norway rats as limiting kiore numbers in New Zealand whereas Atkinson (1973) suggests predation or competition from ship rats has lowered kiore population levels. Taylor (1975, 1978) has further implicated competition from all rodent species, including mice, in New Zealand as affecting kiore density.

Predation may act on populations in many ways (Andersson and Erlinge 1977). The low abundance of rats found in this study supports observations that rodent populations remain at lower abundance where predators are present. Moller and Craig (1987) predict kiore will have a lower density, prolonged breeding, earlier sexual maturation and lower litter size on islands where predators are present. The index of 1.7 kiore/100 trap nights is towards the lower end of the range of trapping success for kiore in New Zealand (Moller and Craig 1987), and the index of 1.8 ship rats/100 trap nights is also towards the lower end of the range of trapping success for ship rats in New Zealand forests (Beveridge 1964, Best 1968, Daniel 1972, Innes 1977, Daniel 1978, Clout

1980, Hickson *et al.* 1986). Apart from the low trap success of Norway rats on four islands in the Bay of Islands (Moller and Tilley 1986), the 0.6 rats/100 trap nights recorded in this study is the lowest Norway rat trap success from New Zealand (Moors 1985). Cats (*Felis catus*) are the main predators of rats in the Robertson River region of Stewart Island (Karl and Best 1982) while moreporks (*Ninox novaeseelandiae*) have been implicated elsewhere in New Zealand (Stead 1936, Daniel 1972). In their study of the diet of cats on Stewart Island, Karl and Best (1982), found rats in 93% of scats collected, and rats contributed 79.7% to the estimated total weight of foods taken with an average of 1.7 rats per scat. This is a higher proportion of rats in cat diet than was found in the Orongorongo Valley (Fitzgerald and Karl 1979). In their study Fitzgerald and Karl suggest that predation by feral cats on ship rats is important in holding rat populations at low densities and in reducing seasonal fluctuations in their numbers. The effect predation will have on rat abundance will depend on the productivity of the rat populations (Fitzgerald and Karl 1979). Immature rats were a smaller proportion of the Norway rat population than was the case for either ship rats or kiore in this study, which suggests Norway rat productivity may be lower than the productivity of the other two species. In addition, the index of abundance of Norway rats was significantly lower and much less variable than the indices of the other two species. Ship rat and kiore abundance showed great seasonal fluctuations whereas Norway rat showed little seasonal variation. These factors together suggest ship rats and kiore may be less affected by predation than Norway rats by virtue of higher productivity. Furthermore, although the species of rats found in the scats on Stewart Island could not be determined (Karl and Best 1982), Norway rats may be more vulnerable to predation as cats might find the larger, ground dwelling, generally less agile Norway rat an easier catch than either of the other two species. Therefore, predation by cats on all three species of rat may in part, or whole, explain the overall low rat abundance on Stewart Island. In addition, proportionately greater predation on Norway rats, together with, their greater sensitivity to the effects of predation as a consequence of their lower productivity, might be responsible for the lower and more stable Norway rat abundance. At times when general rat numbers are low predation on ship rats and kiore may have the effect of increasing the amplitude of fluctuations in their abundance (Andersson and Erlinge 1977, Fitzgerald B.M. 1978) thus accentuating the differences between ship rat and kiore and Norway rat abundance. Further studies on the predator prey relationships between rats and cats on Stewart Island, especially the identification of the species of rat(s) taken by cats, should shed valuable light on the complex interspecific interactions involved.

Overall trapping success of rats on each transect was not significantly different, although each transect differed significantly in species composition. Kiore were generally not present in the two habitats which supported the greatest Norway rat populations, transects B and E. Conversely in the habitat which supported the greatest kiore abundance transect D, only one Norway rat was ever caught. On transect C, where both ship rats and kiore were equally predominant, Norway rats were again scarce. The highest abundance of ship rats was recorded in association with Norway rats in the coastal podocarp forest, transect E, although only slightly lower abundance was recorded in association with Norway rats on transect B and in association with kiore in the mixed forest of transect C. The presence of ship rats in the scrub habitat of transect D is probably a result of dispersing individuals at periods of high abundance. Ship rats were only caught on transect D in winter and spring, when rat abundance was highest each year, and also no mature male ship rats were ever caught on transect D. A similar explanation may be offered for the presence of kiore on transect B.

Therefore, habitat segregation was evident, especially between Norway rats and kiore. Previous trapping on Stewart Island has indicated ship rats to be more widespread than either kiore or Norway rats both of which appear to have a patchy distribution (Choate and Gibbs 1964, Taylor 1975, Gales 1980 in Hickson *et al.* 1986, Hickson *et al.* 1986).

Habitat segregation is one possible outcome of interspecific competition with species being displaced or restricted to preferred habitats (Stoecker 1972, Turner *et al.* 1975). Interspecific competition cannot be assumed to be the sole cause of habitat segregation as habitat preferences are likely to play a part (Morris 1984, Dueser and Porter 1986). Similarly because of the possible outcome of interspecific competition habitat preferences cannot necessarily be inferred from simple correlations between high abundance and presence in particular habitats. Habitat preferences may more appropriately be inferred from comparing abundance of a species in habitats in which that species predominates. However, in this study only four habitats were trapped and this limits the number of comparisons when three species are involved.

A preference of kiore for dry, grassland areas with good cover is suggested by Dick (1985) for kiore on Kapiti Island. Jackson and Strecker (1962) implied kiore on Ponape Island prefer grassland and a similar preference for grassland on Stewart Island is suggested by Taylor (1975) who trapped higher numbers of kiore in grassland than in forest and scrub. A preference of kiore for dry scrub habitat is also inferred from trapping in this study with highest abundance recorded in scrub on transect D, followed in decreasing order of abundance by mixed forest and then the two mature podocarp forests. Such preferences may help to explain the absence of kiore from forest habitats on Stewart Island found by Choate and Gibbs (1964), Gales (1980 in Moller and Craig 1987) and Hickson *et al.* (1986). However, without being able to eliminate the effects of interspecific competition from ship rats and Norway rats, such ideas of habitat preferences must be treated with caution.

Ship rats have predominantly been captured in forest habitats in New Zealand (Daniel 1978), although on Stewart Island they have been trapped in forest, scrub, swampland, grassland and bush (Taylor 1975 and this study). Little difference was evident between the abundance of ship rats in the two podocarp forests (transects B and E) and the mixed forest (transect C) but a much lower abundance was present in the scrub habitat, transect D. Therefore, ship rats attained higher population levels alongside Norway rats on transects B and E and alongside kiore on transect C compared with lower numbers in the scrub on transect D, in which kiore predominated. Whether this represents habitat preferences on the part of ship rats, or is evidence of the fickle nature of interspecific competition is unclear.

Norway rats have also been trapped in a variety of habitats throughout New Zealand but mainly on islands (Daniel 1978, Dick 1985, Moors 1985). On Stewart Island they have been captured in scrub and forest (Taylor 1975 and this study). Dick (1985) concluded that Norway rats on Kapiti Island did not have a particular preference for forest. He suggested that both kiore and Norway rats coveted grasslands but it was Norway rats that dominated in them and he regarded Norway rats to be the superior competitor.

Therefore, it appears that the difficulty in eliminating the effects of interspecific interactions between the three species and thus confidently assigning habitat preferences, is great. The high degree of habitat segregation would suggest that interspecific competition is a feature of the rats on Stewart Island but the possibility that habitat preferences may influence distribution, cannot be ignored.

The captures of rats at known distances from water allows examination of the relationship of each species to a single habitat feature i.e. availability of water. Ship rats displayed a slight preference for closeness to water while Norway rats were invariably caught very close to water and kiore further away. Overall trapping indicated kiore were caught primarily at trap-sites in distance category 5, but this may be an artifact of kiore mainly occurring on transect D where only trap-sites in distance category 5 were available. This is supported by trapping on transect C, where trap-sites in the range of distance categories 1-5 were available yet little evidence of a preference for trap-sites farthest from water was displayed. On transects B and E, where ship rats and Norway rats predominated kiore were caught disproportionately in the highest distance categories. On transect C, where ship rats and kiore predominated, Norway rats were only caught at trap-sites in distance category 1, despite the availability of trap-sites in the whole range of distance categories. Therefore, there was a degree of disassociation between kiore and Norway rats. This supported the ecological separation of kiore and Norway rats found by the overall trapping in all habitats. These findings suggest varying degrees of interspecific competition might be involved. Interspecific competition may result in restriction of coexisting species to habitats which they are most adapted (Schoener 1982). For example the availability of a single habitat feature, water, may confer a competitive advantage upon Norway rats.

Predation may also have a restricting effect on rat distribution (Andersson and Erlinge 1977). Taylor (1978) proposed that it may be differential rodent predation by stoats that limits the Norway rat to a 'patchy' distribution in most of New Zealand. Norway rats appear to be present only in areas close to water thus retaining a patchy distribution in the absence of stoats. Could predation by cats be responsible for this distribution?

4.3 Morphometrics

The body measurements, mean weight and mean head and body length (HBL), of rats indicate that all three species of rat on Stewart Island are smaller than those trapped in other parts of New Zealand (Appendix 5). The method used to measure HBL in this study is not directly comparable to studies which have measured HBL from nose tip to anus, and in some cases in Appendix 5 measurements include only adult rats but these factors are not likely to alter the above statement.

Differences in body size between populations may result from factors such as stress from intraspecific competition (Barnett 1955), social ranking (L.Davis 1979), interspecific competition (Schoener 1982) and environmental conditions such as dietary differences relating to nutrition and energy value of foods (Davis D.E. 1953, Jackson and Barbehenn 1962, Hansson 1971).

Jackson and Barbehenn (1962) found laboratory reared kiore fed a high protein diet reached greater weights than wild populations on Ponape Island. The soil of the Robertson River study area is typically peaty (Leamy 1974) with high acidity (Colbourne and Powlesland unpublished). Peat soils are generally nutrient poor and anaerobic (Hamilton and Hodder 1979) and such nutrient deficiency is likely to be reflected in low abundance and poor nutrient quality of rat foods. This is supported by nutrient analysis on plants from the study area in which low levels of nutrients, particularly nitrogen, were found (R. Powlesland pers comm.). Peat soils are also likely to contain few invertebrates (Colbourne and Powlesland unpublished). Therefore I suggest in comparison to other rat populations in New Zealand the diet of Stewart Island rats is nutrient deficient which is reflected in the recorded low weight and small size of rats trapped.

Interspecific competition might also result in lower weights, either through the stressful effects of direct contact or indirectly through exploitation of limited resources.

Fluctuations in the age structure of the populations are likely to be a major cause of the seasonal variations in the weight of ship rats and kiore. Kiore were lightest in winter and spring. These were the seasons in which the greatest proportions of immature rats were caught and immature rats were significantly lighter than mature rats. Ship rats were lightest in spring followed by winter and most immature rats were trapped in winter indicating that factors other than changes in age structure were affecting weight. Environmental factors such as seasonal changes in food supply both quantitatively and qualitatively may be important.

Ship rats were the only species to show significant differences in weight between transects, the Scheffe test indicating that rats on D were significantly lighter than on E. This difference may also be explained by variation in weight with maturity. Ship rats were only trapped on transect D in winter and spring. As shown above ship rats were lightest in these seasons therefore it would follow that ship rats on transect D will be lighter. Furthermore no mature male ship rats were caught on transect D. Factors such as diet (see section 4.5.2) and interspecific competition may also influence weights between transects.

4.4 Reproduction

4.4.1 Maturity

Determination of male maturity by position of the testes is especially useful in the field. Under autopsy greater precision can be gained by noting the presence of macroscopically visible tubules in the cauda epididymus because the presence of these tubules is correlated with the presence of mature sperm in the cauda epididymus (Jackson 1962). The presence or absence of epididymal tubules was noted for many rats, although data on this condition was incomplete therefore testes position was preferred for analysis. Moors (1985) favoured the presence of mature sperm in the seminiferous tubules as determined by microscopic examination of testes, as the criterion of male maturity; 10% of rats he examined from the Noises Islands would have been incorrectly classified using both testes position and presence/absence of epididymal tubules, a similar error noted by Jackson (1962).

The most accurate measure of female maturity is the presence or absence of corpra lutea in the ovaries because these are always present if ovulation has occurred (Perry 1945). Vaginal perforation is more of an index of maturity (Davis D.E. 1953, Tamarin and Malecha 1971) and is especially useful in the field. This method tends to over estimate the number of mature females in a population (Davis and Hall 1951, Moller and Craig 1987). Daniel (1972) found that perforation of the vagina occurred about a month before ovulation in female ship rats in the Orongorongo Valley.

Although the methods used in this study could in some cases, be improved upon they are an adequate compromise between precision and time constraints and are sufficient to indicate seasonal trends (Tamarin and Malecha 1971).

Marked seasonal changes in the proportions of mature and immature rats were found. Increased proportions of immature rats are likely to be a result of earlier breeding activity, although unknown mortality may influence the calculation of the proportions.

The presence of mature males of each species in each season suggests that the length of the breeding season is likely to be determined by females, although marked seasonal peaks in the proportion of mature males probably indicate peaks in breeding activity. The lower proportions of mature male ship rats in winter, kiore in winter and spring and Norway rats in winter and summer are likely to be caused by the increase of juveniles in the populations and not from a seasonal retraction of the testes. This has not been recorded for any of the three species (Davis and Hall 1948, Davis D.E. 1953, Jackson 1962). Similarly, seasonal periodicity of breeding condition, i.e. seasonal changes in sperm production, has not been reported for adult males of any of these species (Davis D.E. 1953, Jackson 1962, Daniel 1972).

There was little seasonal change in the proportions of mature females. This suggests there is no seasonal closure of the vagina and supports similar findings by Davis and Hall (1951) for Norway rats. Also, few immature females were caught. This may result from the trapping bias towards older individuals in the population as perforation of the vagina may occur at such an early age that few individuals with closed vaginas are trappable.

Recording only macroscopically visible pregnancies is likely to be an underestimation of the number of females pregnant in a population as pregnancies are only visible for a portion of the pregnancy (Davis & Hall 1951). For Norway rats pregnancies are visible for 18 out of the 22-25 days of gestation. This 18 day period was used as the duration of visible pregnancy for each species.

4.4.2 Reproductive Activity

The breeding season may be defined by the presence of pregnant females. However, the very low numbers of pregnant females caught in this study made estimation of the breeding season for each species uncertain. Such a low number of pregnant rats when a large proportion of the females are mature could be the result of several factors. Females may have been avoiding copulation or not meeting males to copulate, or pregnant rats were less trappable than non-pregnant rats, small sample size resulted in low capture rate of pregnant rats or peaks in breeding season were missed in the trapping programme. The large seasonal fluctuations in abundance, especially the increase in ship rat and kiore abundance in winter of each year, corresponding with the increase in juveniles, and the great mobility of rats would suggest that, at least for ship rats and kiore, females were not avoiding copulation and were meeting males to copulate. That pregnant rats are less trappable than others is a possibility. Beveridge and Daniel (1965) suggest the low number of pregnant rats captured on Mokoia Island may be because pregnant rats are more difficult to trap, although this was not tested. Small sample size will result in unreliable results. One possible outcome is that no pregnant rats would be caught. Alternatively if pregnant individuals were caught they are likely to represent an unrealistically high proportion of the catch and thus a high incidence of pregnancy will result. This most likely explains the great increase in the reproductive parameters for Norway rats in 1986 compared to other years, although other factors such as a change in the timing of the breeding season or a real increase in breeding can not be discounted. I believe the major cause of low numbers of pregnant rats is that the peaks in breeding season were missed because of the three monthly spacing of the trapping sessions and the timing of these sessions. Best (1968) found very similar bimodal breeding seasons for ship rats in two south island forests. One of the populations, in a Banks Peninsula forest, had breeding peaks three months apart in November and February-March. The season commenced in September and finished in April. Between the peaks was a period of inactivity in December. If a similar breeding season for ship rats occurred on Stewart Island it is quite conceivable that trapping in September (spring), late November-early-December (summer) and late March (autumn) of each year would miss the peak(s) in breeding activity. Thus low incidence of pregnancy would be recorded. Very similar breeding seasons have been found for ship rats in the Orongorongo Valley (Daniel 1972) and Tiritea Reserve (Innes 1977). A low incidence of winter breeding was recorded in both these studies as was found in this study.

A shorter breeding season is reported for kiore in New Zealand. Dick (1985) recorded a breeding season for kiore on Kapiti Island beginning in spring and peaking in summer with no breeding in winter. The calculated breeding season was just over three months at 139 days. A similar restricted breeding season for kiore, of three or possibly four months was found on Tiritiri Matangi Island (Craig and Moller 1978). Pregnant kiore were trapped in November, December and January and one in February. Again if a similar length of breeding season for kiore occurred on Stewart Island the main breeding peak could have occurred between the three monthly trapping sessions.

Reproduction of Norway rats in New Zealand may occur all year round with a single peak in summer (Beveridge and Daniel 1965, Dick 1985) or between autumn and spring (Bettesworth 1972a, Moors 1985). Daniel (1978) summarizes Norway and ship rat breeding seasons in New Zealand suggesting that they generally last for six to seven months of the year but can continue into autumn and winter following heavy seed and fruit falls in autumn. This pattern of reproduction also corresponds with many overseas studies of Norway rats (Perry 1945, Davis D.E. 1953, Pye and Bonner 1980). Again the time between trapping sessions may have caused the breeding peaks of Norway rats to be missed each year and, because of the low Norway rat population, small sample size could result in few or no captures of pregnant rats even if breeding was continuous at low levels throughout the year(s).

Seasonality of breeding is shown by the annual increased abundance of ship rats and kiore, boosted by large numbers of juveniles. Competition may also restrict the breeding season, easily missed by the timing of the trapping sessions.

The mean number of embryos per pregnant ship rat (5.6) and Kiore (4.67) are similar to those found in other studies from the New Zealand region (Appendix 4) excepting the very high figure recorded for kiore on Tiritiri Matangi Island (Craig and Moller 1978). For Norway rats the mean number of embryos (6.2) is the lowest from the New Zealand region (Appendix 6) and is considerably lower than any quoted by Davis D.E. (1953) who listed a range of 7.5 to 11.2 embryos per female from 27 studies. Calculations of mean foetus number in this study are likely to be an overestimation because no distinction was made between resorbing and viable embryos.

The calculation of incidence of pregnancy and average female annual productivity must be treated with caution considering first the likelihood of trapping having missed the breeding seasons and second the use of breeding season lengths from other studies. With these factors in mind the low incidence of pregnancy figures and low female productivity for each species must be considered tentative. Low incidence of pregnancy of Norway rats has been associated with deficient diet and stable populations (Davis D.E. 1953). Deficient diet has already been suggested as a possible cause of the low weights of rats from Stewart Island and it is likely that nutritional factors also play a part in the low incidence of pregnancies recorded. Stable populations might be expected to have a lower productivity and thus a lower proportion of juveniles compared to increasing (or fluctuating) populations. The maturity results indicate input of juveniles into the populations, although they are likely to be affected by unknown mortality factors. They also show that juveniles make up a much larger proportion of ship rat and kiore numbers than Norway rat numbers. The less variable abundance indices and small proportion of juveniles for Norway rats would suggest that a low incidence of pregnancy may be associated with a less productive, stable population.

The possibility that rat populations have reached a maximum and thus increased social stress and competition was lowering reproductive activity as proposed for Norway rats by Calhoun (1962) is unlikely for Norway rats but may explain the seasonal fluctuations in abundance of ship rats and kiore each year. That this is unlikely for Norway rats is suggested by the overall, very low, stable abundance of Norway rats compared to populations from other habitats in New Zealand (Beveridge and Daniel 1965, Bettesworth 1972a, Dick 1985). Also the incidence of pregnancy was consistently low over four and a half years of trapping, except for the increase in 1986. One would expect that following a population maximum, abundance would begin to decline followed by an increase in the reproductive parameters during the next season. However, even though an increase in incidence of pregnancy was recorded for Norway rats in 1986, this increase was not preceded by high abundance in 1985 and a decrease in early 1986. Ship rats and kiore in Hawaii have been shown to undergo yearly abundance cycles (Tamarin and Malecha 1971), very similar to those found on Stewart Island in this study. These seasonal fluctuations in Hawaii were shown to be intimately linked with the rats reproductive cycles. Abundance was lowest in summer followed by increased breeding activity, recruitment and then a cessation of breeding corresponding with high abundance in winter. Tamarin and Malecha suggest the timing of the breeding season is controlled by environmental factors but the mechanism regulating reproduction is uncertain. They suggest behavioural changes with increased intraspecific interactions at high density inhibiting reproduction, are a possible cause. Other studies have indicated a similar negative correlation between abundance and breeding (Davis D.E. 1953, Bettesworth 1972a). Similar comparisons are not possible in this study because of the lack of reproductive information. However, increased recruitment of immature ship rats in winter and kiore in winter and spring would suggest that peaks in ship rat and kiore breeding would occur at times of low abundance. It must be re-emphasized that the three monthly trapping regime employed in this study, with the real possibility of missing the peak breeding season, makes any inferences about reproductive activity rather speculative.

4.5 Stomach Analysis

4.5.1 Methods

Analysis of gut contents is a standard approach for quantifying the food habits of animals. Other approaches include direct observation of feeding or food remains, faecal analysis, feeding trials and preference experiments. Analysis of stomach contents has two major disadvantages:

(1) the sacrifice of animals

(2) only the composition of the most recent meal is examined

Killing rats on Stewart Islands was not a problem. The effect of examining only the most recent meal could be a serious problem especially if the turnover rate of food through the gut is high. Phillipson *et al.* (1983), for example, suggested the emptying and refilling of *Microtus agrestis* stomachs may occur between 14 and 21 times per day. The limitations associated with this can only be reduced by trapping a large number of animals. The time of day rats were caught may incorporate bias into stomach analysis. If rats were captured, for example at the beginning of their daily or nightly foraging, then a biased assessment of their diet may be gained by looking at half empty stomachs or only their first meals. Similarly if foraging is not random and a similar feeding pattern is employed each night then the time that rats were caught would influence the recorded composition of their diet.

The problems and sources of error associated with the quantification and expression of results of gut analysis have been well covered by Hansson (1970). The major disadvantage of the frequency of occurrence method is that results obtained may not accurately reflect the contribution of items according to volume. This is because quantification by frequency of occurrence tends to over estimate items occurring in small volumes and items which are not easily digested, eg. insect cuticle and pieces of wood, and it tends to under estimate items which occur in large quantities or items which are easily digested, eg. fruit pulp. The visual estimation of volume is a subjective method of quantification (Best 1968, Hansson 1970, Bettesworth 1972a) and may incorporate a certain, and sometimes inconsistent error (Best 1968). The methods used here are basically the same as used by Kami (1966), Best (1968), Bettesworth (1972a), Innes (1977), Dick (1985). A more accurate method of quantification is that used by Fall *et al.* (1971), where food items are sorted and weighed. However, the time available and number of stomachs to analyse suggested this was not feasible for this study.

Cuticle analysis as a technique for examining herbivore diets has been discussed by Dusi (1949), Stewart D.R.M. (1967), Storr (1961) and Vavra and Holechek (1980). The technique was considered useful for the analysis of deer diet by Anthony and Smith (1974), although it has been criticized as a method for examination of possum diet by Dunnet *et al.* (1973) and deer diet by Nugent (1983) Cuticle analysis is best suited to strictly herbivorous animals. The large amount of non-plant diet items found in the stomachs in this study greatly increased processing time. Methods as described by Fitzgerald A.E. (1976) and modified by A. Grant (pers comm.) would be extremely useful for the quantification of the plant component of rat diet, however, in this study the time and complexities required for such detailed investigation mitigated against there use. The production of an extremely detailed reference collection of plants and plant parts from the study area was essential for the success of the cuticle analysis.

4.5.2 Diet

Gradually a clearer picture of the diet of New Zealand populations of ship rats, kiore and Norway rats has emerged and generally the results of this study concur with results from other New Zealand studies, although important differences have been revealed and new information brought to light.

Ship rat

The breakdown of stomach contents into six food categories gives a general overview of diet and indicates where emphasis lies. As expected invertebrates and vegetation predominated in both frequency of occurrence and volume. That plant food provided the greatest volume, followed by invertebrates, supports findings by Best (1968) and Daniel (1973) for ship rat diet in South island forests and the Orongorongo Valley respectively, although Innes (1977, 1979), Clout (1980) and Gales (1982) found for various populations of ship rats in New Zealand that invertebrates predominated with plant foods the next most important category.

This study has shown that an extremely diverse selection of invertebrates and plant items were eaten by ship rats. Wetas were the most common invertebrate food of ship rats found by Best (1968), Daniel (1973) and Innes (1977) and in this study wetas were by far the single most frequent diet item. Wetas remained the most common invertebrate in all seasons and this would appear to be a reflection of their availability as invertebrate sampling in 1986 showed wetas to be common all year round. No decrease in the frequency of wetas was noted during spring and summer when other foods become available as was found by Best (1968). Other commonly eaten invertebrates, for example Opiliones, beetles and spiders, showed seasonal variation in occurrence which also reflected their seasonal availability. Lepidoptera larvae were commonly eaten by ship rats but were not captured in the invertebrate sampling suggesting either a strong preference for Lepidoptera larvae, as was implied for kiore and Norway rats on Kapiti Island by Dick (1985), or that Lepidoptera larvae escaped capture in the invertebrate sampling.

Cuticle analysis revealed that a very diverse range of plant items were eaten by ship rats. Best (1968), Daniel (1973) and Innes (1977) found fruit and seeds predominated in the plant fraction of ship rat diet. In this study again fruit and seeds were extremely common with the two items unidentified seeds and/or rhizomes and miro fruit the most frequently eaten plant items. However, leaf material, which included leaf, leaf buds and green stems recorded the highest overall frequency of occurrence and a much greater utilization of leaf material is suggested than has previously been reported for ship rats in New Zealand (Best 1968, Daniel 1973, Innes 1977, Campbell 1978). With such a large proportion of the diet comprising vegetation-eating invertebrates such as wetas and stick insects, it is probable that some of the plant material found in the rats stomachs, especially leaves, will be from the gut contents of these ingested animals. Therefore, the leaf material fraction of diet will be overestimated. Best (1968) found green leaf material to be the most common food item in the stomach contents of ship rats from two South Island forests but the volume of such material was so low that this class of food was not considered important. From both feeding trials and stomach analysis Innes (1977) found green leaf material was not an important constituent of ship rat diet. Daniel (1973) found green leaf material to comprise 10% of ship rat diet in the Orongorongo valley but believed this to represent finely chewed leaves from the crops of wetas and not green leaves eaten by rats. With wetas occurring in 85% of ship rat stomachs leaves from weta guts are likely to comprise a part of the leaf material found in the rats stomachs in this study. The initial washing process may have reduced this component of the plant material, but it was unlikely to eliminate it. Cuticle analysis on weta guts indicated there was a maximum length to cuticles found in them. Many of the leaves found in the stomachs of rats occurred as cuticles much larger than would occur in weta guts and in quantities (although no measurements were taken) that would suggest they were in fact eaten by the rats and not ingested with invertebrate gut contents. Of particular note were the several leaf items that were commonly eaten, including the dwarf mistletoe *Korthalsella salicornioides*, which was the third most frequent plant item, rimu, manuka and *Luzuriaga parviflora* leaves and the moss *Cyathophorum bulbosum*. Therefore several leaf items appeared to be important components of ship rat diet on Stewart Island.

Many other leaves only occurred as cuticles of a size consistent with those found in weta stomachs and these may have come from the ingested contents of weta guts. However, rats are notorious for breaking down food into very small pieces. Another source of error likely to be included in the vegetation component of diet is incidental ingestion of items when consuming a target food. Noting whether a plant cuticle was only present in stomachs may suggest which, if any, items are likely to be incidentally ingested. Rat foraging behaviour may involve sampling or tasting many potential foods, therefore because an item was only present, and never abundant, in the stomachs does not necessarily mean that the rats did not intend to eat them.

Birds were a minor component of ship rat diet on Stewart Island in this study. This supports similar findings of low levels of bird consumption for ship rats in New Zealand by Best (1968), Daniel 1973) and Innes (1977), although Gales (1982) found a much higher frequency of occurrence of bird remains from a sample of Stewart Island ship rats. The distinction between bird predation and scavenging could not be made by the examination of remains in the stomachs, although if predation was occurring the gut analysis suggests it was at low levels. For extremely rare birds, such as kakapo, which were present in the study area, any predation would have an extremely significant effect on their continued survival. The ship rat irruption on Big South Cape Islands (Bell 1978) gave a clear indication of the potential ship rats have for the destruction of bird life.

Other vertebrate remains were also found in ship rat stomachs. Some of these were most probably from scavenging other rat carcasses in the traps before they were collected. No lizard or gecko remains were found in the stomachs of ship rats despite their presence in the study area.

Habitat was shown to influence ship rat diet as significant differences were found in the relative frequencies of individual diet items between transects. However, there was much overlap and differences involved changes in the frequency of a few diet items reflecting their availability on the transects. Plant foods provided the most variation between habitats as occurrence of invertebrates in ship rat stomachs was fairly consistent in all populations. The lack of podocarp fruit and seeds on transect D, especially miro, may have led to the greater consumption of alternative plant foods found in ship rat diet on this transect. This may have in turn rendered transect D a less suitable habitat for ship rats, which might explain the low abundance on this transect D. The presumably lower quality of vegetative plant foods as opposed to fruits may be reflected in the lower weights of ship rats on this transect. Nevertheless, with the absence of podocarp fruits and seeds, other fruit, for example *Cyathodes juniperina*, became more important.

A seasonal shift in diet emphasis has been recorded for ship rats in New Zealand. Daniel (1978) summarized ship rat diet suggesting plant foods, especially fruit and seeds, predominated in autumn and winter and invertebrates were most important in spring and summer. Such a clear seasonal shift in the importance of these food categories was not found in this study as both invertebrates and vegetation remained regularly eaten all year round. There was no clear predominance in the volume of vegetation in autumn and winter or invertebrates in spring and summer. Peak volume of vegetation did occur in winter and the volume of invertebrates was lowest in winter. This indicated that the major seasonal shift in diet emphasis, was away from invertebrates and towards vegetation in winter. This appears to be a direct relationship between the availability of these food categories in the study area. The invertebrate sampling showed that invertebrate numbers were lowest in winter. The phenology results revealed great species variation in growth and reproductive phases of the sampled plants with no clear season of vegetative growth for all species. Fruiting season varied considerably for each species, although presence of ripe fruit and seedfall predominated in autumn and winter while some fruit and seed was present in all seasons. Therefore reduction in the importance of invertebrates with a corresponding increase in plant consumption in winter, is a reflection of the seasonal availability of these two food categories. Examination of individual plant items relative frequency of occurrence indicates that the increase in fruit, seed and *Korthalsella salicornioides* consumption in winter were mainly responsible for the seasonal variation found in ship rat diet.

Differences were found in diet composition between weight classes, although again, much overlap was evident and trends in basic diet components were difficult to establish. Age and sex related foraging strategies indicated by diet selection have been reported for ship rats by Clark (1980) and Gales (1982). Clark (1980) reported cohort dependent foraging strategies for ship rats from the Galapagos Islands with age (size) related changes in the proportion of animal foods in diet. In six populations, all showed a negative correlation between percentage of animal food and size of rat; the correlation was significant in four of the six cases. In one breeding population mature females ate significantly more animal material than did mature males. Gales (1982) found juveniles and mature females included significantly more animal food, particularly wetas, in their diet than did mature males on Stewart Island. The hypothesis mooted by these authors being that the demands of growth and reproduction require proportionately more protein and a diet containing more animal foods and therefore of higher protein quality would fulfil this requirement (Gales 1982). However, in this study no such difference between smaller, presumably younger and growing, rats and larger individuals was suggested by the weight class results. Wetas, by far the single most common diet item were eaten heavily by all weight classes, although a slight decrease in frequency did occur in the heaviest weight class. Other invertebrate groups showed no overall trend towards greater consumption by smaller weight classes. No differences were found between the diets of male and female rats. Therefore it appears unlikely from this diet study, that age and sex dependent foraging strategies existed for ship rats. Possibly the extra nutritional demands of growth and reproduction are met by a diverse diet, although this suggests a wider range of food items would be eaten by younger, growing rats and females compared to mature males. The results of this study did not suggest this and was not tested.

Ship rat diet from the Robertson River Region of Stewart Island as revealed by stomach analysis in this study can best be described as opportunistic and expresses the truly generalist qualities of ship rats.

Kiore

The few studies on kiore diet in New Zealand indicate kiore is much more omnivorous in New Zealand than in more tropical regions. This study supports this belief as kiore diet was dominated by invertebrates on both frequency of occurrence and volume criteria and a wide range of plant items were eaten.

New Zealand studies on kiore show animal foods are common diet components. Bettesworth (1972b) found animal material to contribute over 60% of kiore diet on Red Mercury Island. This included almost equal proportions of insects and bird remains and also remains of a skink. Plant foods predominated in kiore stomachs from Korapuki Island (Red Mercury Islands), although a very high frequency of bird down was recorded (Hicks *et al.* 1975). Dick (1985) found invertebrates predominated in the diet of kiore from Kapiti Island. The findings of Fleet (1972) and Campbell *et al.* (1984) together with the implications of Crook (1973), Whitaker (1973) and McCallum (1986) suggest animal foods are important components of kiore diet.

These studies are all at variance with several Pacific island studies which have indicated that plant foods predominate in the diet of kiore with only small amounts of animal foods, mostly insects (Strecker and Jackson 1962a, Kami 1966, Fall *et al.* 1971, Mosby *et al.* 1973, Twimbell 1973). This in part reflects the habitats in which the rats were trapped because all were studies conducted, at least in part, in association with agriculture and crops. It is also likely that in the tropics herbivory predominates as a result of a more reliable plant food supply compared to temperate regions where seasonality affects availability of diet items (Dick 1985). This is further supported by the findings of Fleet (1972) who showed heavy predation of red tailed tropic birds by kiore only occurred in years where storms destroyed their usual supply of plant foods. In New Zealand, it is likely that because of seasonality, and thus greater variation in the availability of plant foods, animal foods should form a larger part of kiore diet

The frequency of invertebrate type eaten on Stewart Island differs from that found from the stomachs of kiore on Kapiti Island by Dick (1985). He found Lepidoptera larvae were the most commonly eaten invertebrate followed in decreasing frequency by spiders, Diptera and wetas. Campbell *et al.* (1984) found weta were the most common invertebrate remains left at husking stations on Tiritiri Island, followed by Coleoptera, Mollusca, Lepidoptera and Diptera. In contrast to both these studies, Diptera were not common in the stomachs of kiore from Stewart Island. The absence of spiders from the husking stations, as reported by Campbell *et al.* (1984), is unusual since only abdomens and legs were ever found in the stomach contents of rats and never the hard head or thorax. These parts, therefore, might be expected to be left at husking stations. The high frequency of occurrence of Lepidoptera larvae in kiore stomachs together with the absence of them from the invertebrate sampling suggests a strong preference for these invertebrates. Dick (1985) also suggested Lepidoptera larvae were a preferred food of kiore on Kapiti Island. Amphipods and earthworms were also found to be extremely common in contrast to Dick (1985) who found few earthworms and only one littoral zone amphipod. Generally the high frequencies of occurrence of many invertebrate types emphasizes the predominance of invertebrates in kiore diet on Stewart Island.

The reliance of kiore on invertebrates is further evidenced by examination of the frequencies of occurrence of plant items. Campbell (1978) has listed a large range of plants and plant parts known to be eaten by kiore. The only plant item to be regularly consumed by kiore in this study was unidentified seed and/or rhizome, although many plant items were eaten. Overall, leaf material was the most common plant fraction, although as with ship rats, the probability that gut contents of ingested invertebrates, particularly wetas, contribute to this fraction suggests that leaf material may be overestimated. Greater quantification of these fractions would be necessary to reduce uncertainty. Predominance of seed in the plant fraction of kiore diet was found by Dick (1985).

Apart from invertebrates and vegetation only wood was frequently eaten but the volume of this category suggests this was a minor diet component. No vertebrate items were found in kiore stomachs. The lack of bird and lizard remains suggests kiore may be less of a threat to these species than the other rats supporting similar conclusions by Dick (1985). He found no bird remains in the stomachs of kiore from Kapiti Island but did find the remains of skink in one. Bettesworth (1972b) also found the remains of a skink in a kiore stomach from Red Mercury Island. Evidence from Fleet (1971) together with the implications from Crook (1973), Whitaker (1973), Atkinson (1978) and McCallum (1986) would suggest kiore can have detrimental effects on vertebrates in certain situations.

Habitat did not affect kiore diet. This may reflect the predominance of invertebrates in the diet because the combined results of both invertebrate sampling methods indicate that overall, differences between invertebrate faunas on each transect were not great. Habitat was shown to influence kiore diet on Kapiti Island (Dick 1985), although Strecker and Jackson (1962a), examining a wide range of habitats on Ponape Island found little variation in kiore diet.

Kiore diet was affected by season. The major changes were general increases in occurrence of invertebrate items in spring and summer and an increase in consumption of plant items in autumn and winter. This trend was reflected in the seasonal volume of invertebrate and vegetation eaten, although only in autumn was vegetation volume greater than invertebrate. This may suggest a preference for available plant material in autumn because, although night sampling recorded lowest numbers of invertebrates in this season, pitfall trapping showed there was still a high availability of invertebrates, including those eaten by kiore.

Norway rats

A generally varied, omnivorous diet for Norway rats has been reported in New Zealand. Plant foods, particularly seeds, constituted the major diet component of Norway rats on Mokoia Island (Beveridge and Daniel 1965) and on Kapiti Island (Dick 1985). Invertebrate and vertebrate foods were found to predominate in Norway rat diet on Whale Island (Bettesworth 1972a) while invertebrates were the most important constituent of Norway rat diet on the Noises Islands (Moors 1985). Invertebrates predominated in both frequency of occurrence and volume in this study but volume estimates showed vegetation and vertebrate were important diet components.

Although invertebrates were very common in Norway rat diet only a few types were regularly eaten. Freshwater crayfish (koura) were the single most frequently eaten item and Opiliones and wetas were also commonly taken. Norway rat predation has been implicated in the decline of koura in New Zealand by Buller (1870) and Johnson (1870). Beveridge and Daniel (1965) suggest freshwater crayfish are a food source of Norway rats on Mokoia Island, Lake Rotorua, although the presence of koura in stomachs in this study appears to be the first direct evidence of Norway rat predation. The high frequency of occurrence of freshwater crayfish suggests feeding on crayfish is common among Norway rats and is not just the result of a few individuals having learnt the behaviour. Whether the rats dive for and capture the crayfish underwater or take them on land could not be determined. The ability of freshwater crayfish to walk considerable distances and survive long periods of time on land (R. Fordham pers comm.) suggests they may be able to leave the water in suitable situations, where they would be easy prey for a rat. The streams and waterways on each transect contained many shallow, muddy, flood channels in which crayfish may exist or survive during dry periods. Presumably koura in these muddy channels would be easy prey for rats. Norway rats have been observed diving for freshwater molluscs in the river Po, Italy (Nieder *et al.* 1982, Nieder *et al.* in press) and Johnson (1870) reported that Norway rats dive for freshwater mussels and open them on the stream bank. Beveridge and Daniel (1965) also suggest freshwater mussels are taken from Lake Rotorua and eaten on the shore of Mokoia Island. Buller (1870) quotes a letter from the Reverend T.

Chapman in which he states " The natives assure me that the Norway rat caught crayfish by diving." The occurrence of stonefly larvae would also suggest an underwater foraging behaviour for Norway rats on Stewart Island but again stonefly larvae may survive on land and terrestrial forms do exist (McLellan 1977). In any case the high occurrence of these "predominantly" aquatic invertebrates in Norway rat stomachs coupled with the close relationship with water indicated by trapping, would suggest that in the Robertson River region of Stewart Island a very important correlation exists between Norway rats and streams.

A wide range of plant items are eaten by Norway rats (Beveridge and Daniel 1965, Campbell 1978, Dick 1985, Moors 1985). They principally comprise fruit and seeds but seedlings, rhizomes, roots and bark have also been recorded as eaten (Campbell 1978). Few plant items were eaten extensively on Stewart Island with fruit and possibly seeds and leaf material being the main plant components. The low frequencies of occurrence of individual plant items emphasizes the predominance of animal foods in Norway diet found in this study. Leaf material was commonly eaten but again this may be an overestimation because of the probable occurrence of gut contents from weta and other invertebrates, although the moss *Cyathophorum bulbosum* stands out as being an important diet item.

Habitat has been shown to influence Norway rat diet in New Zealand. Beveridge and Daniel (1965) found mostly fruit and seeds in the diet of Norway rats on Mokoia Island but seedlings and invertebrates were also important. Shags and other birds were eaten near the shore. Bettesworth and Anderson (1972) found the diet of Norway rats on Whale Island changed from the shore inland. Along the foreshore and boulder banks insect remains and intertidal invertebrates predominated but inland, flesh and down of the grey faced petrel *(Peterodroma macroptera)* was the major diet component. Bettesworth (1972a) found the importance of petrel flesh and eggs to be directly related to the density of breeding birds in different areas on Whale Island. The importance of seeds and invertebrates in Norway diet also varied with habitat on Whale Island. Moors (1985) found insects, seeds, fruit and other plant material, especially *Solanum*, comprised the major diet components of Norway rat diet on the Noises Islands. Littoral zone invertebrates were also extremely important. Dick (1985) also found that Norway rat diet varied with habitat on Kapiti Island, the major variation occurring in the importance of seed and other vegetation.

Although diet differed between transects on Stewart Island, there was much overlap. Fruit, beetles and aquatic invertebrates were the major cause of variation. Littoral zone invertebrates might have been expected to occur as a fraction of Norway rat diet on transect E, although the small beach was at the end of the trapline and few of the sampled rat population were likely to have access to it. Few ground nesting birds such as petrels were present in the habitats trapped explaining their absence from the diet.

Sooty shearwaters (*Puffinus griseus*) did occur in low numbers on scattered headlands but were unlikely occur on any of the transects (D. Cunningham pers comm). Fiordland crested penguins (*Eudyptes pachyrhynchus*) were present at the beach at Maori Bay and may have nested in the caves there but they were not likely to be accessible to most of the sampled population. Kiwis were present and remains of kiwi were found in one Norway rat stomach, although whether this was from predation or scavenging could not be established. No kakapo remains were found in any rat stomachs.

Season has also been found to influence Norway rat diet in New Zealand. On Mokoia Island Norway rats caused extensive damage to forest seedlings but this was confined to winter when other food sources were less abundant (Beveridge and Daniel 1965). The significance of petrel flesh and eggs in Norway rat diet on Whale Island is intimately related to the seasonal pattern of the petrel breeding cycle (Bettesworth 1972a). Daniel (1978) summarized both ship rat and Norway rat diet in New Zealand stating that seeds and fruit are the main foods eaten in autumn and winter. However, this does not hold for Norway rats on Stewart Island, in this study. The mean percentage volume of invertebrates was greater than the vegetation component for each season. There was however, a seasonal aspect to both the volume and occurrence of these two diet components. Consumption of vegetation was considerably greater in both autumn and winter compared to spring and summer, and volume of vegetation peaked in winter. Both fruits and other vegetation were eaten more often in autumn and winter. Invertebrates were the predominant food eaten in all seasons with volume peaking in summer. Seasonal occurrence of individual invertebrate types was variable but a general trend towards greater usage in spring or summer was noted. Overall frequency of occurrence of invertebrates was lowest in spring which corresponded with the peak consumption of vertebrates. Spring peaks in the proportion of bird remains were found in ship rat stomachs by Best (1968) and Innes (1977). The increase in proportion of vertebrates eaten maybe due to increased vulnerability to predation of birds during breeding and the presence of chicks and eggs. Other sources of vertebrate remains were also recorded, i.e. lizard and mammal, and are likely to influence the seasonal proportions of vertebrate eaten. The presence of skinks in Norway rat stomachs has been recorded by Dick (1985) and this study indicates they form a small component of Norway rat diet on Stewart Island.

Therefore an extremely varied diet for Norway rats on Stewart Island is reported and this parallels other New Zealand studies of Norway rat diet. Unique diet items, of both invertebrates and plants are recorded and overall an opportunistic dietary habit is suggested.

Diet Synthesis

The diet of all three species may best be described as opportunistic. Diet appeared to reflect the availability of a wide variety of invertebrates, plant items and other foods. However, certain diet preferences and/or restrictions appeared to exist for each species, and although much overlap occurred significant differences in the diet of each species were found.

Examination of the frequency of occurrence and mean percentage volume estimates of the six food categories suggests Norway rats have a more varied diet than either ship rats or kiore, but within the two major food categories of invertebrates and vegetation Norway rats displayed less diversity as fewer invertebrate types and fewer plant items were eaten. Ship rats were the greatest opportunists with the most diverse diet. Kiore were most reliant on invertebrates, although a greater range of specific diet items was eaten compared to Norway rats.

Invertebrates appeared to be extremely important for each species but Norway rats and kiore in particular, showed a greater reliance on them than ship rats. A greater diversity of plant items were eaten by ship rats and vegetation was a greater proportion of ship rat diet than for either kiore or Norway rats.

The characteristic food items of each species' diet suggest different foraging strategies exist between the three species of rat on Stewart Island. Wetas were by far the most frequent item eaten by both ship rats and kiore and they were consumed considerably more often than by Norway rats. Wetas, stick insects, miro fruit, *Korthalsella salicornioides* and broadleaf stem buds and stems were all characteristic of ship rat diet and are also, all mainly arboreal food types, although wetas and miro fruit do commonly occur on the ground. A mixture of ground dwelling and arboreal food types characterized kiore diet. Worms and amphipods are predominantly ground dwelling whereas wetas and spiders occur both at ground level and higher. *Korthalsella salicornioides*, which parasitizes manuka, was significant in separating kiore and ship rat diet from Norway rat diet but it occurred much more frequently in ship rat diet than in kiore diet. Frequencies of occurrence of other invertebrates indicated ground dwelling types were more often eaten by kiore. Therefore, comparison of diet items suggest ship rats are predominantly arboreal foragers and feed on the ground to a lesser extent whereas kiore are mainly ground feeders and forage less in the trees. Freshwater crayfish were by far the most frequent item eaten by Norway rats and the presence of this invertebrate was the most striking characteristic of Norway rat diet. Such a predominance of the aquatic invertebrates, freshwater crayfish and stonefly larvae, is unique and unreported in other studies on Norway rat diet in New Zealand, although other authors have alluded to their consumption. The predominance of koura and stonefly larvae suggest that streams and waterways are a major feeding niche of the Norway rat on Stewart Island and emphasize a reliance on water that was indicated by Norway rats' trapping. The other major diet items, Opiliones, wetas, spiders, carabid beetles, unidentified seeds and/or rhizomes and *Cyathophorum bulbosum* imply a predominantly ground level foraging strategy for the Norway rat. These different foraging strategies shown by different diet items may reduce possible competition between the species in two ways; first, by reducing competition over limited food, and second, by reducing the amount of physical contact between the species. These aspects of diet may in turn be factors in the unique coexistence of the three species on Stewart Island.

The presence of vertebrate material was characteristic of ship rat and Norway rat diet and possibly indicated that kiore were less of a threat to the bird life of Stewart Island than the other two species. Norway rats showed a greater utilization of vertebrates than did ship rats and the only lizard remains occurred in Norway rat stomachs, although a similar frequency of occurrence of bird remains was noted.

The occurrence of other diet items, for example wood, fungus and other material, suggest that all species may have a foraging behaviour which involves the sampling of many different food items.

Overall,the diet of each species indicated that invertebrates and plant material were the basic diet foods but that a very large range of invertebrates, plants and other foods were eaten. Best (1968) suggested when the normal nutritional requirements of ship rats become increasingly more difficult to be met by the basic diet components of invertebrates and vegetation, specifically fruit and seeds, the rats will utilize a wider range of food sources. This hypothesis was suggested to explain the greater level of bird predation by ship rats in Banks Peninsula forest compared to ship rats in Waimangaroa forest. The Banks Peninsula forest was less diverse in plant species and probably less abundant in invertebrate life than the Waimangaroa forest, and thus nutritionally deficient in comparison. Best also applied this theory to the ship rat irruption on Big South Cape Islands (Bell 1978).

The nutrient-poor, peat soils of the Robertson River region are likely to result in low biomass and poor nutrient quality of many rat foods, particularly invertebrates and fruit and seeds. Therefore, the hypothesis proposed by Best (1968) may apply to all species, and may in part, explain the very large number of diet items, and the uniqueness of many items, eaten by the rats on Stewart Island. The extremely large range of foods eaten may therefore represent attempts at satisfying their normal nutritional requirements that presumably could not be met by a narrow range of invertebrates, fruits and seeds. This hypothesis would require that diet selection be determined by nutrient requirements. Clark (1980) and Gales (1982), in finding age and sex related foraging strategies for ship rats on the Galapagos Islands and Stewart Island respectively suggest protein quality may be a major determinant of ship rat diet.

Moors (1985) found female Norway rats on the Noises Islands included more animal foods in their diet during the breeding season than did males, suggesting extra demands for proteins during reproduction could have been a major factor influencing diet selection. Reichman (1977), however, found energy requirements to be the major determinant of heteromyid rodent diet.

Interspecific competition may also have a large influence on the composition of each species diet. Exploitation of the same foods when all or part are limited in availability is a commonly cited source of competition among small animals (Pontin 1982) and rodents in particular (Grant 1972). However, the evidence for this form of competition is scarce (Grant 1972) and probably reflects the difficulty in measuring it.

The phenology recordings and invertebrate sampling indicated the seasonal availability of many plant parts and invertebrate types in 1986. Fruiting and seeding, previously recorded as the main plant foods of all species, was minimal in 1986, although some fruit and seed from the plants sampled was present all year round. Comparisons between the diet and phenological recordings indicate many potential plant foods were not eaten and others were selectively eaten by each species. Generally the invertebrates that predominated in the invertebrate sampling were also those that were common in the diets of each species of rat, although differences between the diets and the sampling results, and differences between the diets of each species indicated preference and selection was a feature of invertebrate feeding. However, it must be remembered that phenology and invertebrate sampling was confined to 1986 whereas diet analysis covered rats trapped from June 1982 and therefore the unknown conditions of previous years vegetation and invertebrate availability are incorporated into the diet results.

To establish if these foods were limited in their availability resulting in competition between the rat species would require knowledge of the nutrient and energy requirements of the rats and the ability of the foods to satisfy those requirements. Phenology recordings revealed that fruit and seed availability was low in 1986 and invertebrate sampling suggests if food was limiting, competition would be most severe in winter when invertebrate numbers were lowest, corresponding with highest rat abundance.

Much overlap in diet was found between the three rat species on Stewart Island and level of overlap may be associated with intensity of competition (Jaeger 1974), but overlap in resource use does not necessarily indicate competition is occurring. It may in fact be evidence that competition is not occurring thus coexistence is by virtue of lack of competition and populations are held down by other factors, for example predation (Schoener 1982).

The diet of each species, although showing much overlap, was qualitatively different from each other and from previously recorded diets in New Zealand and elsewhere. One plausible outcome of interspecific competition is changes or shifts in the diet of the species involved (Pontin 1982). This would have the effect of reducing interspecific competition, possibly allowing coexistence. However, one can not automatically assume that these findings indicate shifts in diet as a result of interspecific competition. The modifying effects of other factors such as food availability in different habitats and diet preferences may also be involved. A corollary of such diet shifts is that coexistence in most habitats would be probable, although varying degrees of habitat segregation is a feature of this region.

4.6 Competition and Coexistence

Competition has been observed in many animal populations (Barnett and Spencer 1951, Stoecker 1972, Jaeger 1974, Turner *et al.* 1975, Pontin 1982, Heske *et al.* 1984, Dueser and Porter 1986, Bowers *et al.* 1987), and Grant (1972) has suggested that competition for space is a general phenomenon among rodent populations.

A characteristic feature of the ecology of ship rats, kiore and Norway rat in the pacific and New Zealand region is variation in their degree of association. Competitive interactions between these species in the pacific region have been suggested by Kami (1966), McCartney (1970), Williams (1973), and Twimbell (1973). Watson (1956, 1961), Williams (1973), Atkinson (1973) and Taylor (1975, 1978) have offered explanations involving interspecific competition between rodents to account for the observed distribution of the rat species in New Zealand. Taylor's (1978) view (page 6) fairly represents the current position.

As revealed in the introduction, the coexistence of the three rat species on Stewart Island is so far unique to the New Zealand region and is therefore central to Taylor's (1978) theory. Despite coexistence of all three species, marked habitat delineation exists, suggesting interspecific competition may be a feature of the Stewart Island rat populations. However, because so few habitats were trapped in this study, the effect that habitat preferences has on distribution can not be isolated.

Competition between Norway rats and kiore has been suggested by Meeson (1884), White (1897), Watson (1956, 1961), Twimbell (1973), Williams (1973) and Dick (1985). In this study the greatest degree of habitat separation was observed between these two species. Generally kiore were not present where Norway rats occurred and Norway rats were absent in habitats occupied by kiore. Further separation was suggested by the trapping relationships with water; Norway rats were captured in close proximity to water. Dick (1985) found allopatry rather than sympatry was characteristic of Norway rat and kiore occurrence on Kapiti Island. He concluded that competition was a feature of their association and that Norway rats were the dominant competitor. Norway rats predominated in grasslands on Kapiti, a habitat which both rats appear to covet (Dick 1985, Williams 1973, Taylor 1975), but kiore were present in forest. Trapping was not conducted in grassland during my study but Taylor (1975) conducted trapping in grassland in Northern Stewart Island and caught only ship rats and kiore. It may be that under certain habitat conditions kiore gain a competitive advantage over Norway rats on Stewart Island but the availability of water may confer a competitive advantage upon Norway rats. Therefore, the exclusion of kiore from the inland and coastal podocarp forests, transects B and E, may be a result of competition with Norway rats, the larger more aggressive Norway rat faring better in physical exchanges (Twimbell 1973).

The association of kiore and ship rats in the mixed forest, transect C, suggests that competitive exclusion might not be a feature of their coexistence on Stewart Island, and therefore, competition from ship rats may not be a factor in the exclusion of kiore from transects B and E. This assumes that competition, or lack of it, is constant between habitats, an assumption with dubious merits. Few records of ship rat and kiore coexisting in New Zealand exist. They are both present on Arapawa Island (in Atkinson 1978), Great Barrier Island (in Atkinson 1978, 1986) and Taylor (1975) trapped ship rats and kiore in the same habitats in Northern Stewart Island. They have been recorded coexisting in several localities throughout the pacific (Storer 1962, Kami 1966, Fall *et al.* 1971, Twimbell 1973, Tamarin and Malecha 1971). No interspecific competition was recorded between coexisting ship rats and kiore on Ponape Island, either in the field (Barbehenn and Strecker 1962) or in experimental enclosures (Strecker and Jackson 1962b). However, ecological separation was observed with kiore mainly foraging at ground level whereas ship rats displayed greater arboreality, and in grassland kiore were more diurnal where the nocturnal ship rats were present. Therefore where food, nest sites and space are not limited physical contact was avoided by ecological separation in time and space. A similar separation in space was suggested by the diet of kiore and ship rats in this study. Where ship rats and kiore coexist physical contact may be avoided by ship rats climbing trees and kiore remaining on the ground. A similar scenario may be envisaged for ship rat and Norway rat coexistence, this is also suggested by Twimbell (1973) and supported by the diet analysis in this study. For kiore and Norway rats this option is reduced. Therefore it appears likely that interference between kiore and ship rats may not be a factor excluding kiore from the podocarp forests, transects B and E, or excluding ship rats from the scrub habitat, transect D.

It may be that the single habitat feature, availability of water, confers a competitive advantage upon Norway rats which are otherwise restricted by competition from kiore and/or ship rats or by predation from cats. Therefore it may be that on transects B and E, both habitats closely associated with streams, Norway rats gain a competitive advantage over kiore and kiore are excluded. On transect C, trapping was conducted across the side of a south facing slope with a water channel in the valley at the bottom. Norway rats were restricted to areas close to this water course most likely by either a competitive advantage held by kiore further up the slope or by predation from cats. Ship rats exist on all three habitats possibly avoiding competition by virtue of greater use of their arboreal proclivities. On transect D, the lack of a water course renders this habitat less suitable for Norway rats and kiore appear to hold the competitive advantage. If ship rats remain predominantly arboreal in the presence of kiore then the lack of arboreal habitat in this scrub and possibly the lack of podocarp fruiting species may render this transect less suitable for ship rats. Hence resources such as food and nest-sites may be limiting and kiore may have the competitive advantage over ship rats. Thus habitat preferences and interspecific competition may together influence distribution of the three rat species on Stewart Island. The occasional captures of kiore on transect B and E and ship rats on D are most likely to be the result of dispersal at high abundance (Stoecker 1972).

Interference competition, particularly between kiore and Norway rats, might then be a factor influencing rat distribution in this region. Negative behavioural interactions are a commonly cited form of interspecific competition between rodents (Barnett and Spencer 1951, Grant 1972, Twimbell 1973). A corollary of such interaction is that the intensity of competition would increase with increasing density; the greater the density the greater the chance of contact. Stoecker (1972), Turner *et al.* (1975), and Heske *et al.* (1984) suggest such behavioural aggression linked with changes in reproductive states is a determinant of microtine rodent distribution in North America. If this form of competition was occurring on Stewart Island then habitats with highest abundance would be expected to have the least degree of coexistence while seasonal fluctuations in abundance should have related changes in degree of coexistence. Furthermore a reduction in coexistence should be observed during the breeding seasons.

The abundance of rats on each transect were very similar yet varying degrees of coexistence occurred. This neither supports nor contradicts the predicted changes in coexistence because different factors were involved, eg. different habitat characteristics. More appropriately, comparison of coexistence during fluctuations in abundance on the same habitat should test such predictions. However, on no habitat were the predicted seasonal changes in coexistence observed. Few pregnant rats were trapped and it was probable that trapping was not conducted during the breeding season (section 4.4 page 88) and therefore this aspect could not be examined. Hence observations supporting interference competition on Stewart Island are not obvious. Examination of other resources possibly responsible for competition would help to clarify the situation.

The low level of nutrients thought to occur in this region may affect the rats in several ways:

(1) Low abundance of invertebrates and other rat foods is a likely product of low nutrients in the ecosystem, and this may then result in low rat abundance.

(2) Rats may spend longer foraging for food and as a consequence the chance of contact between the three species would be greater.

(3) The rats might also be forced to use a wider range of food items (Best 1968).

These factors would suggest that competition for food is a likely occurrence on Stewart Island, primarily as a result of low availability of preferred food. Intensity of this form of competition would be most acute in winter when rat abundance was highest and food availability, particularly invertebrates, was lowest. Therefore one would expect to observe a decrease in coexistence during this season but this was not evident from the trapping results. Although considerable overlap existed, differences in diet suggest that competition for available food may be reduced by each species adopting different foraging strategies. Norway rats appeared to use aquatic and ground level foraging, kiore mainly ground level and ship rats predominantly arboreal foraging. This would not only reduce competition for available food but would also reduce the chance of contact between each species. Such foraging strategies also suggest that competition may be most severe between kiore and Norway rats and therefore the least degree of coexistence would be expected between these two species.

Alternatively the dampening effect of predation and dispersal on abundance may be keeping numbers at levels which allow stable coexistence to result, such that the variation in habitat association may reflect habitat preferences and competition may not be a feature of the rat populations in this region.

Pontin (1982) has emphasized the need for experimental evidence to support ecological observation of competition. Addition and removal experiments involving all four rodent species and their predators, and experimental manipulation gf resources are needed to rigorously test theories on competition in New Zealand. It is timely that experimental manipulation of the populations, their resources and their predators be undertaken. Only then will the effects of competition, habitat preferences and predation on the coexistence of ship rat, kiore and Norway rats be more clearly understood.

REFERENCES

ANDERSSON M.; ERLINGE S. (1977). Influence of predation on rodent populations. Oikos 29: 591-597.

ANTHONY R.G.; SMITH N.S. (1974). Comparison of rumen and faecal analysis to describe deer diet. Journal of Wildlife Management 3: 535-540

ATKINSON I.A.E. (1973). Spread of the ship rat (Rattus r. rattus L.) in New Zealand. Journal Royal Society of New Zealand 3: 457-472.

ATKINSON I.A.E. (1978). Evidence for effects of rodents on the vertebrate wildlife of New Zealand Islands. In The ecology and control of rodents in New Zealand nature reserves. Pp. 7-31. Dingwall P.R.; Atkinson I.A.E.; Hay C. (eds.). Department of Lands and Survey Information Series No.4, Wellington.

ATKINSON I.A.E. (1986). Rodents on New Zealand's northern offshore islands: Distribution, effects and precautions against further spread. In The offshore islands of northern New Zealand. Pp. 13-40. Wright A.E.; Beever R.E. (eds.). New Zealand Department of Lands and Survey Information Series No.16, Wellington.

BARBEHENN K.R.; STRECKER R.L. (1962). Intra- and interspecific behaviour. A: Field data. In Pacific Island Rat Ecology: Report of a study made on Ponape and adjacent islands 1955-1958. Pp. 166-173. Storer T.I. (ed.). Bernice P. Bishop Museum Bulletin 225.

BARNETT S.A. (1963). The Rat: A study in behaviour. The University of Chicago Press, Chicago. 318pp.

BARNETT S.A. (1955). Competition among wild rats. Nature 75: 126-127.

BARNETT S.A.; SPENCER M.M. (1951). Feeding, social behaviour and interspecific competition in wild rats. Behaviour 3: 229-242.

BELL B.D. (1978). The Big South Cape islands rat irruption. In The ecology and control of rodents in New Zealand nature reserves. Pp. 33-40. Dingwall P.R.; Atkinson I.A.E.; Hay C. (eds.). Department of Lands and Survey Information Series No.4, Wellington.

BEST H.A. (1982). An appraisal of kakapo research and management. Unpublished Wildlife Service Report. Pp. 45.

BEST L.W. (1968). The ecology of *Rattus rattus rattus* (L) in selected areas of the South Island, New Zealand. Unpublished M.Sc thesis, University of Canterbury.

BEST L.W. (1969). Food of the roof rat *Rattus rattus rattus* (L) in two forest areas of New Zealand. New Zealand Journal of Science 12: 258-267.

BETTESWORTH D.J. (1972a). Aspects of the ecology of *Rattus norvegicus* on Whale Island, Bay Of Plenty, New Zealand. Unpublished M.Sc thesis, University of Auckland

BETTESWORTH D.J. (1972b). *Rattus exulans* on Red Mercury Island. Tane 18: 117-118.

BETTESWORTH D.J.; ANDERSON G.R.V. (1972). Diet of *Rattus norvegicus* on Whale Island, Bay Of Plenty, New Zealand. Tane 18: 189-194.

BEVERIDGE A.E. (1964). Dispersal and destruction of seed in central North Island podocarp forests. Proceedings of the New Zealand Ecological Society 11: 48-55.

BEVERIDGE A.E.; DANIEL M.J. (1965). Observations on a high population of brown rats (*Rattus norvegicus* Berkenhout 1767) on Mokoia Island, Lake Rotorua. New Zealand Journal of Science 8: 174-189.

BOWERS M.A.; THOMPSON D.B.;BROWN J.H. (1987). Spatial organisation of a desert rodent community: food addition and species removal. Oeclogia 72: 77-82.

BROWN J.H.; MUNGER J.C. (1985). Experimental manipulation of a desert rodent community: food addition and species removal. Ecology 66: 1545-1563.

BULLER W.L. (1870). Further notes on the ornithology of New Zealand. Transactions of the New Zealand Institute 3: 37-56

CALHOUN J.B. (1962). The ecology and sociology of the Norway Rat. United States Department of Health, Education and Welfare.

CAMPBELL D.J. (1978). The effects of rats on vegetation. In The ecology and control of rodents in New Zealand nature reserves. Pp. 99-120. Dingwall P.R.; Atkinson I.A.E.; Hay C. (eds.). Department of Lands and Survey Information Series No.4, Wellington.

CAMPBELL D.J.; MOLLER H.; RAMSAY G.W.; WATT J.C. (1984). Observations on foods of kiore (*Rattus exulans*) found in husking stations on northern Offshore islands of New Zealand. New Zealand Journal of Ecology 7: 131-138.

CHOATE T.; GIBBS W.A. (1964). Small mammal investigations on Stewart Island. Science Record 14: 84-85.

CLARK D.A. (1980). Age- and sex- dependent foraging strategies of a small mammalian omnivore. Journal of Animal Ecology 49: 549-563.

CLOUT M.N. (1980). Ship rats (*Rattus rattus* L) in a *pinus radiata* plantation. New Zealand Journal of Ecology 3: 141-145.

COLBOURNE R.; POWLESLAND R.G. (Unpublished). Diet of the Stewart Island brown kiwi (*Apteryx australis lawryi*) at Scollay's Flat southern Stewart Island.

CONNER H.E.; EDGER E. (1987). 1960-1986 and Nomina Nova IV 1883-1986. New Zealand Journal of Botany 25: 115-170.

CRAIG J.L. (1983). Rodents of the greater Auckland region. Tane 29: 215-222.

CRAIG J.L. (1986). The effects of kiore on other Fauna. In The offshore islands of northern New Zealand. Pp. 75-83. Wright A.E.; Beever R.E. (eds.). New Zealand Department of Lands and Survey Information Series No.16, Wellington.

CRAIG J.L.; MOLLER H. (1978). The ecology of kiore (*Rattus exulans*) on Tiritiri Matangi Island. In The ecology and control of rodents in New Zealand nature reserves. Pp. 175-176. Dingwall P.R.; Atkinson I.A.E.; Hay C. (eds.). Department of Lands and Survey Information Series No.4, Wellington.

CROOK I.G. (1973). The tuatara, *Spenodon punctatus* Gray, on islands with and without populations of the Polynesian rat, *Rattus exulans* (Peale). Proceedings of the New Zealand Ecological Society 20: 115-120.

CUNNINGHAM D.M.; MOORS P.J. (1983). A guide to the identification and collection of the New Zealand rodents. New Zealand Wildlife Service, Department of Internal Affairs Publication No.4

DANIEL M.J. (1969). A survey of rats on Kapiti Island, New Zealand. New Zealand Journal of Science 12: 363-372.

DANIEL M.J. (1972). Bionomics of the ship rat (*Rattus r. rattus*) in a New Zealand indigenous forest. New Zealand Journal of Science 15: 313-341.

DANIEL M.J. (1973). Seasonal diet of the ship rat (*Rattus r. rattus*) in lowland forest in New Zealand. Proceedings of the New Zealand Ecological Society 20: 21-30.

DANIEL M.J. (1978). Population ecology of ship and Norway rats in New Zealand. In The ecology and control of rodents in New Zealand nature reserves. Pp. 145-152. Dingwall P.R.; Atkinson I.A.E.; Hay C. (eds.). Department of Lands and Survey Information Series No.4, Wellington.

DANIEL M.J.; WILLIAMS G.R. (1984). A survey of the distribution, seasonal activity and roost sites of New Zealand bats. New Zealand Journal of Ecology 7: 9-25.

DAVIS D.E. (1953). The characteristics of rat populations. The Quarterly Review of Biology 28: 373-401.

DAVIS D.E.; HALL O. (1948). The seasonal reproductive condition of male brown rats in Baltimore, Maryland. Physiological Zoology 21: 272-282.

DAVIS D.E.; HALL O. (1951). The seasonal reproductive condition of female (brown) rats in Baltimore, Maryland. Physiological Zoology 24: 9-20.

DAVIS L.S. (1979). Social rank behaviour in a captive colony of Polynesian rats (*Rattus exulans*). New Zealand Journal of Zoology 6: 371-380.

DELANY M.J. (1974). The ecology of small mammals. Edward Arnold, London. 66 pp.

DICK A.M.P. (1985). Rats on Kapiti Island, New Zealand: Coexistence and diet of *Rattus norvegicus* Berkenhout and *Rattus exulans* Peale. Unpublished M.Sc. thesis, Massey University.

DIXON W.J.; MASSEY F.J. (1969). Introduction to statistical analysis. McGraw-Hill, New York.

DUESER R.D.; PORTER J.H. (1986). Habitat use by insular small mammals: relative effects of competition and habitat structure. Ecology 67: 195-201.

DUNNET G.M.; HARVIE A.E.; SMIT T.J. (1973). Estimating the proportions of various leaves in the diet of the opposum, *Trichosurus vulpecula* Kerr, by faecal analysis. Journal of Applied Ecology 10: 737-745.

DUSI J.L. (1949). Methods for determination of food habits by plant microtechniques and histology and their application to cottontail rabbit food habits. Journal of Wildlife Management 13: 295-298.

EMLEN J.T. Jnr.; DAVIS D.E. (1948). Determination of reproductive rates in rat populations by examination of carcasses. Physiological Zoology 21: 59-65.

FALL M.W.; MEDINA A.B.; JACKSON W.B. (1971). Feeding patterns of *Rattus rattus* and *Rattus exulans* on Eniwetok Atoll, Marshall Islands. Journal of Mammology 52: 69-76.

FITZGERALD A.E. (1976). Diet of the opposum, *Trichosurus vulpecula* (Kerr) in the Orongorongo Valley, Wellington, New Zealand, in relation to food-plant availability. New Zealand Journal of Zoology 3: 399-419.

FITZGERALD A.E.; WADDINGTON D.C. (1979). Comparison of two methods of fecal analysis of herbivore diet. Journal of Wildlife Management 43: 468-473.

FITZGERALD B.M. (1978). Population ecology of mice in New Zealand. In The ecology and control of rodents in New Zealand nature reserves. Pp. 163-171. Dingwall P.R.; Atkinson I.A.E.; Hay C. (eds.). Department of Lands and Survey Information Series No.4, Wellington.

FITZGERALD B.M.; KARL B.J. (1979). Foods of feral house cats (*Felis catus* L.) in forest of the Orongorongo Valley, Wellington. New Zealand Journal of Zoology 6: 107-126.

FLACK A.D.; LLOYD B.D. (1978). The effect of rodents on the breeding success of the South Island Robin. In The ecology and control of rodents in New Zealand nature reserves. Pp. 59-66. Dingwall P.R.; Atkinson I.A.E.; Hay C. (eds.). Department of Lands and Survey Information Series No.4, Wellington.

FLEET R.R. (1972). The nesting success of the Red-Tailed Tropicbird on Kure Atoll. Auk 89: 651-659.

FLOWERDEW J.R. (1976). Techniques in mammology, Chapter 4. Ecological methods. Mammal Review 6: 123-159.

GALES R.P. (1982). Age- and sex-related differences in diet selection by *Rattus rattus* on Stewart Island, New Zealand. New Zealand Journal of Zoology 9: 463-466.

GRANT P.R. (1972). Interspecific competition among rodents. Annual Review of Ecological Systematics 3: 79-106.

GURNELL J. (1978). Observations on trap response in confined populations of woodmice, *Apodemus sylvaticus*. Journal of Zoology, London 185: 279-287.

GURNELL J. (1982). Trap response in woodland rodents. Acta Theriologica 27: 123-137.

HAMILTON L.S.; HODDER A.P.W. (1979). Proceedings of a symposium on New Zealand Peatlands, Hamilton 23-24 November, 1978. Hamilton, University of Waikato.

HANSSON L. (1967). Index line catches as a basis of population studies on small mammals. Oikos 18: 261-276.

HANSSON L. (1970). Methods of morphological diet micro-analysis in rodents. Oikos 21: 255-266.

HANSSON L. (1971). Small rodent food, feeding and population dynamics: a comparison between granivorous and herbivorous species in Scandinavia. Oikos 22: 183-198.

HESKE E.J.; OSTFIELD R.S.; LIDICKE W.Z.Jnr. (1984). Competitive interactions between *Microtus californicus* and *Reithrodontonmys megalotis* during two peaks of *Microtus* abundance. Journal of Mammology 65: 271-280.

HICKS G.R.F.; McCOLL H.P.; MEADS M.J.; HARDY G.S.; ROSER R.J. (1975). An ecological reconnaissance of Korapuki Island, Mercury Islands. Notornis 22: 195-220.

HICKSON R.E.; MOLLER H.; GARRACK A.S. (1986). Poisoning rats on Stewart Island. New Zealand Journal of Ecology 9: 111-121.

HITCHMOUGH R.A. (1980). Kiore (*Rattus exulans*) on Motukawanui Islands, Cavalli Group, northern New Zealand. Tane 26: 161-168.

HOWARD B. (1974). Rakiura. A history of Stewart Island, New Zealand. A.H. and A.W. Reed. Dunedin and Wellington.

IMBER M.J. (1978). The effect of rats on breeding success of petrels. In The ecology and control of rodents in New Zealand nature reserves. Pp. 67-72. Dingwall P.R.; Atkinson I.A.E.; Hay C. (eds.). Department of Lands and Survey Information Series No.4, Wellington.

INNES J.G. (1977). Biology and ecology of the ship rat *Rattus rattus rattus* (L) in Manawatu (New Zealand) forests. Unpublished M.Sc. thesis, Massey University.

JACKSON W.B. (1962). Reproduction. In Pacific Island Rat Ecology: Report of a study made on Ponape and adjacent islands 1955-1958. Pp. 92-107. Storer T.I (ed.). Bernice P. Bishop Museum Bulletin 225.

JACKSON W.B.; BARBEHENN K.R. (1962). Growth and development. In Pacific Island Rat Ecology: Report of a study made on Ponape and adjacent islands 1955-1958. Pp. 80-89. Storer T.I (ed.). Bernice P. Bishop Museum Bulletin 225.

JACKSON W.B.; STRECKER R.L. (1962). Ecological distribution and relative numbers. In Pacific Island Rat Ecology: Report of a study made on Ponape and adjacent islands 1955-1958. Pp. 45-63. Storer T.I (ed.). Bernice P. Bishop Museum Bulletin 225.

JAEGER R.G. (1974). Competitive exclusion: Comments on survival and extinction of species. Bioscience 24: 33-39.

JENSEN T.S. (1975). Trappability of various functional groups of the forest rodents, *Clethrionomys glareolus* and *Apodemus flavicollis*, and its application in density estimations. Oikos 26: 196-204.

JOHNSON Captain. (1870). On certain changes in the habits of rats at Raglan. Proceedings of the Auckland Institute, In Transactions of the New Zealand Institute 3: 47.

KAMI H.T. (1966). Foods of rodents in the Hamakua District, Hawaii. Pacific Science 20: 367-373.

KARL B.J.; BEST H.A. (1982). Feral cats on Stewart Island; their foods, and their effects on kakapo. New Zealand Journal of Zoology 9: 287-294.

LEAMY M.L. (1974). Soils of Stewart Island (Rakiura), New Zealand. New Zealand Soil Survey Report 22, Wellington, DSIR.

LEATHWICK J.R. (1984). Phenology of some common trees, shrubs and lianes in four central North Island forests. F.R.I. Bulletin No. 70. 46pp.

LINN I.J.; DOWNTON F. (1975). The analysis of data obtained from small mammal index trapping. Acta Theriologica 20: 319-331.

MACARTHUR R.H.; WILSON E.O. (1967). The theory of island biogeography. Princeton University Press. 203 pp.

McCALLUM J. (1986). Evidence of predation by kiore upon lizards from the Mokohinau Islands. New Zealand Journal of Ecology 9: 83-87.

McCARTNEY W.C. (1970). Arboreal behaviour of the Polynesian rat (*Rattus exulans*). Bioscience 20: 1061-1062.

McLELLAN I.D. (1977). New alpine and southern Plecoptera from New Zealand, and a classification of the Gripopterygidae. New Zealand Journal of Zoology 4: 119-147.

MEESON B.A. (1884). The plague of rats in Nelson and Marlborough. Transactions and Proceedings of the New Zealand Institute 17: 199-207.

MOEED A.; MEADS M.J. (1985). Seasonality of pitfall trapped invertebrates in three types of native forest, Orongorongo Valley, New Zealand. New Zealand Journal of Zoology 12: 17-53.

MOLLER H.; CRAIG J.L. (1987). Ecology of *Rattus exulans* on Tiritiri Matangi Island. New Zealand Journal of Zoology 14: 305-328.

MOLLER H.; TILLEY J.A.V. (1986). Rodents and their predators in the Eastern Bay of Islands. New Zealand Journal of Zoology 13: 563-572.

MOORS P.J. (1983). Predation by mustelids and rodents on the eggs and chicks of native and introduced birds in Kowhai Bush, New Zealand. Ibis 125: 137-154.

MOORS P.J. (1985). Norway rats (*Rattus norvegicus*) on the Noises and Motukawao Islands, Hauraki Gulf, New Zealand. New Zealand Journal of Ecology 8: 37-54.

MORRIS D.W. (1984). Patterns and scale of habitat use in two temperate zone, small mammal faunas. Canadian Journal of Zoology 62: 1540-1547.

MOSBY J.M.; WODZICKI K.; THOMPSON H.R. (1973). Food of the kimoa (*Rattus exulans*) in the Tokelau Islands and other habitats in the Pacific. New Zealand Journal of Science 16: 799-810.

NELSON L.Jnr.; CLARK F.W. (1973). Correction for sprung traps in catch/effort calculations of trapping results. Journal of Mammology 54: 295-298.

NEW ZEALAND METEOROLOGICAL SERVICE (1983). Summaries of climatological observations to 1980. New Zealand Meteorological Service Miscellaneous publication 177. Government Printer, Wellington.

NIEDER L.; CAGNIN M.; DREWETT R. (in press). Freshwater molluscs predation by wild rats, *Rattus norvegicus* (Berk.). Acta Zoologica Fennica.

NIEDER L.; CAGNIN M.; PARSI V. (1982). Burrowing and feeding behaviour in the rat. Animal Behaviour 30: 837-844.

NUGENT G. (1983). Deer diet estimation by rumen or faecal analysis: An evaluation of available techniques. F.R.I. Bulletin 24.

PELIKAN J. (1969). Testing and elimination of the edge effect in trapping small mammals. In Energy flow through small mammal populations. Pp. 57-61. Petrusewicz K.; Ryskowski L. (eds.). PWN, Warsaw.

PERRY J.S. (1945). The reproduction of wild brown rats. Proceedings of the Zoological society, London. 115: 19-46.

PETTICREW B.G.; SADLIER R.M.F.S. (1970). The use of index trap lines to estimate population numbers of deermice (*Peromyscus maniculatus*) in a forest environment in British Columbia. Canadian Journal of Zoology 48: 385-389.

PHILLIPSON J.; SARRAZIN-COMANS M.; STOMATOPOULOS C. (1983). Food consumption by *Microtus agrestis* and the unsuitability of faecal analysis for the determination of food preference. Acta Theriologica 28: 397-416.

PONTIN A.J. (1982). Competition and coexistence of species. Pitman, London. 102 pp.

PYE T.; BONNER W.N. (1980). Feral brown rats, *Rattus norvegicus*, in South Georgia (South Atlantic Ocean). Journal of Zoology, London 192: 237-255.

RAMSAY G.W. (1978). A review of the effect of rodents on the New Zealand invertebrate fauna. In The ecology and control of rodents in New Zealand nature reserves. Pp. 89-97. Dingwall P.R.; Atkinson I.A.E.; Hay C. (eds). Department of Lands and Survey Information Series No.4, Wellington.

REICHMAN O.J. (1977). Optimisation of diets through food preferences by heteromyid rodents. Ecology 58: 454-457.

ROSENWEIG M.L. (1973). Habitat selection experiments with a pair of coexisting heteromyid rodent species. Ecology 54: 111-117.

RYSZKOWSKI L. (1969). Operation of the standard-minimum method. In Energy Flow Through Small Mammal Populations. Pp. 13-24. Petrusewcz K.; Ryszkowski L. (eds.). PWN, Warsaw.

SANSOM O. (1982). In the grip of an island: Early Stewart Island history. Craig Printing Co. Ltd., Invercargill. 172 pp.

SCHOENER T.W. (1982). The controversy over interspecific competition. American Scientist 70: 586-595.

SMIT F.G.A.M. (1979). The fleas of New Zealand (Siphonaptera). Journal of the Royal Society of New Zealand 9: 143-232.

SMITH M.H.; GENTRY J.B.; GOLLEY F.B. (1969). A preliminary report of small mammal census methods. In Energy Flow Through Small Mammal Populations. Pp. 25-29. Petrusewcz K.; Ryszkowski L. (eds.). PWN, Warsaw.

SOKAL R.R.; ROHLF F.J. (1969). Biometry: The Principles And Practice Of Statistics In Biological Research. Freeman and Company, 776 pp.

SOUTHERN H.N. (1964). The handbook of British Mammals. Blackwell Scientific Publications, Oxford. 465 pp.

STEAD E.F. (1936). The Maori rat. Transactions and Proceedings of the Royal Society of New Zealand 66: 178-181.

STEWART A.P. (1979). Trapping success in relation to trap placement with three species of small mammals, *Rattus fuscipes, Antechinus swainsonii* and *A. stuarii*. Australian Wildlife Research 6: 165-172.

STEWART D.R.M. (1967). Analysis of plant epidermis in faeces: A technique for studying the food preferences of grazing herbivores. Journal of Applied Ecology 4: 83-111.

STICKEL L.F. (1948). The trap line as a measure of small mammal populations. Journal of Wildlife Management 12: 153-161.

STOECKER R.E. (1972). Competitive relations between sympatric populations of voles (*Microtus montanus* and *M. pennsylvanicus*). Journal of Animal Ecology 41: 311-329.

STORER T.I. (1962). Pacific Island Rat Ecology: Report of a study made on Ponape and adjacent islands 1955-1958. (Editor). Bernice P. Bishop Museum Bulletin 225.

STORR G.M. (1961). Microscope analysis of faeces, a technique for ascertaining the diet of herbivorous mammals. Australian Journal of Biological Science 14: 157-165.

STRECKER R.L. (1962). Population levels. In Pacific Island Rat Ecology: Report of a study made on Ponape and adjacent islands 1955-1958. Pp. 74-79. Storer T.I (ed.). Bernice P. Bishop Museum Bulletin 225.

STRECKER R.L.; JACKSON W.B. (1962a). Habitats and habits. In Pacific Island Rat Ecology: Report of a study made on Ponape and adjacent islands 1955-1958. Pp. 64-73. Storer T.I (ed.). Bernice P. Bishop Museum Bulletin 225.

STRECKER R.L.; JACKSON W.B. (1962b). Intra- and interspecific behaviour. B: Data from captive rats. In Pacific Island Rat Ecology: Report of a study made on Ponape and adjacent islands 1955-1958. Pp. 173-176. Storer T.I (ed.). Bernice P. Bishop Museum Bulletin 225.

TAMARIN R.H.; MALECHA S.R. (1971). The population biology of Hawaiian rodents: Demographic parameters. Ecology 52: 383-394.

TAYLOR R.H. (1975). What limits kiore (*Rattus exulans*) distribution in New Zealand. New Zealand Journal of Zoology 2: 473-477.

TAYLOR R.H. (1978). Distribution and interactions of rodent species in New Zealand. In The ecology and control of rodents in New Zealand nature reserves. Pp. 135-141. Dingwall P.R.; Atkinson I.A.E.; Hay C. (eds.). Department of Lands and Survey Information Series No.4, Wellington.

TOMICH Q.R.; KAMI H.J. (1966). Coat colour inheritance of the roof rat in Hawaii. Journal of Mammology 47: 423-431.

TURNER B.N.; PERRIN M.R.; IVERSON S.L. (1975). Winter coexistence of voles in spruce forest: Relevance of seasonal changes in aggression. Canadian Journal of Zoology 53: 1004-1011.

TWIMBELL J. (1973). The ecology of rodents in the Tonga Islands. Pacific Science 27: 92-98.

VAVRA M.; HOLECHEK J.L. (1980). Factors influencing microhistological analysis of herbivore diets. Journal of Range Management 35: 371-374.

WATSON J.S. (1956). The present distribution of *Rattus exulans* (Peale) in New Zealand. New Zealand Journal of Science and Technology 37: 560-570.

WATSON J.S. (1961). Rats in New Zealand: A problem of interspecific competition. Proceedings of the Ninth Pacific Science Congress 19: 15-16.

WHITAKER A.H. (1973). Lizard populations on islands with and without Polynesian rats, *Rattus exulans* (Peale). Proceedings of the New Zealand Ecological Society 20: 121-130.

WHITAKER A.H. (1978). The effects of rodents on reptiles and amphibians. In The ecology and control of rodents in New Zealand nature reserves. Pp. 75-88. Dingwall P.R.; Atkinson I.A.E.; Hay C. (eds.). Department of Lands and Survey Information Series No.4, Wellington.

WHITE T. (1897). On rats and their nesting in small branches of trees. Transactions and Proceedings of the New Zealand Institute 30: 303-309.

WILDLIFE RESEARCH LIAISON GROUP (1984). (WRLG). Research on rodents in New Zealand. Research Review No. 4.

WILLIAMS J.M. (1973). The ecology of *Rattus exulans* (Peale) reviewed. Pacific Science 27: 120-127.

APPENDIX 1: Raw Trapping Data and Indices of Abundance

	Kiore							Ship rat							Norway rat							Total	Trap	Index of
Date	A	B	C	D	E	Tot	Index	A	B	C	D	E	Tot	Index	A	B	C	D	E	Tot	Index	Captures	Nights	Abundance
June 82	0	0	0	3	1	4	0.7	1	8	3	1	2	15	2.8	0	2	0	0	0	2	0.4	21	534.5	3.9
Sept 82	4	0	0	3	1	8	1.4	1	3	1	1	2	8	1.4	1	0	0	0	1	2	0.3	18	583.5	3.1
Dec 82	2	0	7	6	0	15	1.6	0	2	1	0	4	7	0.8	0	1	0	0	0	1	0.1	23	925.0	2.5
Mar 83	0	0	0	1	0	1	0.1	0	2	3	0	1	6	0.7	3	1	0	0	1	5	0.6	12	917.5	1.3
June 83	5	1	7	6	0	19	2.2	0	4	3	0	1	8	0.8	0	2	1	0	1	4	0.5	30	879.5	3.4
Dec 83	-	0	4	5	0	9	1.5	-	1	1	0	1	3	0.7	-	1	1	0	1	3	0.5	16	604.0	2.6
Mar 84	-	0	2	3	0	5	0.8	-	1	5	0	6	12	1.8	-	1	0	0	2	3	0.5	20	659.5	3.0
June 84	-	2	7	5	0	14	2.5	-	8	6	3	8	25	4.4	-	4	0	0	2	6	1.1	45	563.5	8.0
Sept 84	-	0	2	9	0	11	1.9	-	3	4	1	3	11	1.9	-	3	1	0	0	4	0.7	26	583.5	4.5
Dec 84	-	0	2	7	1	10	1.7	-	1	0	0	2	3	0.5	-	1	0	0	7	8	1.3	21	601.5	3.5
Mar 85	-	0	4	4	0	8	1.3	-	0	1	0	1	2	0.2	-	1	0	0	3	4	0.7	14	604.5	2.3
Jun 85	-	1	3	25	0	29	5.6	-	8	10	7	14	39	7.4	-	3	0	0	1	4	0.7	72	538.0	13.4
Sept 85	-	1	4	5	0	10	1.9	-	6	1	1	8	16	3.0	-	1	1	1	2	5	0.8	31	576.0	5.7
Dec 85	-	0	3	5	0	8	1.3	-	0	2	0	6	8	1.3	-	0	1	0	2	3	0.5	19	598.0	3.2
Mar 86	-	0	0	5	0	5	0.8	-	1	1	0	4	6	1.0	-	2	0	0	1	3	0.5	14	604.0	2.3
June 86	-	0	7	7	6	20	3.4	-	3	6	1	6	16	2.7	-	1	0	0	1	2	0.3	38	583.5	6.5
Sept 86	-	0	2	8	0	10	1.7	-	1	1	0	4	6	1.0	-	2	1	0	0	3	0.5	20*	605.0	3.3
Dec 86	-	0	0	3	1	4	0.7	-	3	0	0	1	4	0.7	-	1	1	0	1	3	0.5	11	612.5	1.8
Totals	11	5	54	110	10	190	1.6	2	55	49	15	74	195	1.7	4	27	7	1	26	65	0.6	451	11573.5	3.9

* = one scavenged unknown species included.

Data from June 1982 to December 1985 provided by D. Cunningham and P. Moors (Department of Conservation).

APPENDIX 2

(a) Multiway analysis of variance on index of abundance under log transformation

Cochran's univariate homogeneity of variance test

C (4,48) = 0.076 p = 0.238

	F	p
Species	22.71	< 0.001
Season	15.84	< 0.001
Transect	0.81	0.489
Species x season	4.87	< 0.001
Species x transect	30.22	< 0.001
Species x season x transect	0.795	0.704

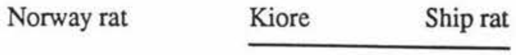
(b) Scheffe Test on Index of Abundance

Multiple range tests, using the Scheffe method; testing for differences in the index of abundance between species, seasons and transects.

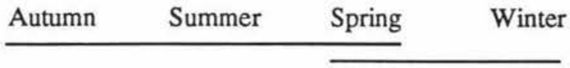
Species, seasons and transects are ranked in order of mean index of abundance for each group; lowest on the left - highest on the right.

—— links groups not significantly different at the 0.05 level.

(1) Index of Abundance x Species



(2) Index of Abundance x season



(3) Index of Abundance x Transect

No two groups significantly different at the 0.05 level.

APPENDIX 3

Distances from Trap-sites to nearest Water**

Trapsite	Transect B	C	D	E
1	1*	1	5	1
2	1*	2	5	1
3	2	4	5	1
4	2	5	5	1
5	2	5	5	1
6	3	5	5	1
7	3	5	5	1
8	3	5	5	1
9	1*	5	5	1
10	1*	5	5	1
11	3	5	5	1
12	3	5	5	1
13	1	3	5	1
14	1	1	5	1
15	2	1	5	1
16	2	1	5	1
17	3	3	5	2
18	3	2	5	2
19	2	4	5	1
20	2	5	5	1
21	2	5	5	1
22	3	1	5	1
23	2	-	5	1
24	2	-	5	1
25	3	-	5	1
26	-	-	5	1
27	-	-	5	2
28	-	-	5	1
29	-	-	5	-

Distance Categories

1	0 - 5m
2	5 - 10m
3	10 - 15m
4	15 - 20m
5	>20m

* = standing water (flood channel/pond/swamp)

** Information collected by D. Cunningham (Department of Conservation)

APPENDIX 4

(a) Multiway Analysis of Variance On Weights

* = $p < 0.05$

** = $p < 0.01$

*** = $p < 0.001$

	Ship rat	Kiore	Norway rat
	F	F	F
Sex	1.572	13.753***	4.787*
Season	2.815*	12.790***	0.265
Transect	2.689*	0.599	1.707
Sex x season	0.462	3.383*	0.332
Transect x season	0.587	1.295	0.844

(b) MANOVA Parameter estimates for analysis of variance on weights -significant interactions only

Ship rat

(1) Season	coefficient
autumn	17.804
winter	-2.235
spring	-11.236
summer	4.333

(2) Transect	coefficient
B	4.264
C	-0.703
D	-21.551
E	17.630

Kiore

(1) Sex	coefficient
M	3.861
F	-3.861

(2) Season	coefficient
autumn	15.108
winter	-16.277
spring	-8.417
summer	9.586

(3) Sex x Season	coefficient
M - autumn	3.505
F - autumn	-3.505
M - winter	-3.541
F - winter	3.541
M - spring	-2.295
F - spring	2.295
M - summer	2.331
F - Summer	-2.331

Norway rat

(1) sex	coefficient
M	19.298
F	-19.298

APPENDIX 4 continued

(c) Scheffe Test on Weights

Multiple range tests, using the Scheffe method, testing for differences in weight of rats between seasons and transects.

Seasons and transects are presented in order of average weight of rats in each group, lightest on the left - heaviest on the right.

—— links groups not significantly different at the 0.05 level.

Ship rat

(1) Weight x Season

(2) Weight x Transect

Kiore

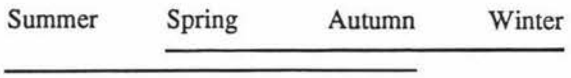
(1) Weight x Season

(2) Weight x Transect

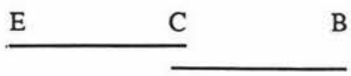
No two groups significantly different at the 0.05 level

Norway rat

(1) Weight x Season



(2) Weight x Transect*



* Transect D was omitted from the analysis because only one Norway rat was ever captured on this transect.

APPENDIX 5

(a) Mean Weights of rats from the New Zealand region

Study area	sex	x̄ weight(g)	n	refrerence
Ship rats				
Tiritea reserve	M	140.0	170	Innes (1977)
	F	125.0	131	
Orongorongo valley	M	145.6	69	Daniel (1972)
	F	115.4	55	
Waimangaroa	M	162.0	44	Best (1969)
	F	134.7	45	
Banks Peninsula	M	160.1	53	Best (1969)
	F	137.5	75	
Stewart Island	M	124.2	96	This study
	F	116.3	87	
Kiore				
Kapiti Island	M	85.9	60	Dick (1985)
	F	79.0	59	
Red Mercury Island	M(scrotal)	102.5	11	Bettesworth (1972b)
	M(non-scrotal)	78.7	4	
	F(perforate)	79.9	10	
Korapuki Island	M(adult)	106.9	8	Hicks *et al.* (1975)
	F(adult)	96.6	11	
	juvenile	30.4	11	
Stewart Island	M	65.6	92	This study
	F	60.8	78	
Norway rat				
Kapiti Island	M	209.8	84	Dick (1985)
	F	222.1	82	
Whale Island	M	273.1	8	Bettesworth & Anderson (1972)
	F	226.3	8	
Mokoia Island	M(mature)	233	66	Beveridge & Daniel (1965)
	F(mature)	245	75	
	M(immature)	108	5	
	F(immature)	99	7	
Motukawao Islands	M(mature)	285	11	Moors (1985)
	F(mature)	246	6	
Noises Islands	M(mature)	267	6	Moors (1985)
	F(mature)	255	18	
Wawaetorea Island	M	210	58	Moller & Tilley (1986)
	F	200	47	
Stewart Island	M	201.4	25	This study
	F	165.5	36	

APPENDIX 5 continued

(b) Mean Head and Body lengths (HBL) of rats from the New Zealand region

Study area	sex	$\bar{x}$ HBL(mm)	n	reference
Ship rats				
Tiritea reserve	M	174.0	172	Innes (1977)
	F	165.8	133	
Orongorongo valley	M			Daniel (1972)
	F			
Waimangaroa	M	190	42	Best (1969)
	F	175	44	
Banks Peninsula	M	187	53	Best (1969)
	F	175	73	
Stewart Island	M	147.1	100	This study
	F	145.4	90	
Kiore				
Kapiti Island	both	140.8	120	Dick (1985)
Red Mercury Island	M(scrotal)	157.4	11	Bettesworth (1972b)
	M(non-scrotal)	155.2	4	
	F(perforate)	147.4	10	
Korapuki Island	M(adult)	306.7*	8	Hicks *et al.* (1975)
	F(adult)	298.0*	11	
	juvenile	153.7*	11	
Stewart Island	M	118.3	94	This study
	F	116.0	81	
	both	117.2	175	
Norway rat				
Kapiti Island	both	180.3	165	Dick (1985)
Whale Island	M	213.5	8	Bettesworth & Anderson (1972)
	F	196.4	8	
Mokoia Island	M(mature)	187	66	Beveridge & Daniel (1965)
	F(mature)	192	75	
	M(immature)	108	5	
	F(immature)	99	7	
Motukawao Islands	M(mature)	206	11	Moors (1985)
	F(mature)	190	8	
Noises Islands	M(mature)	215	7	Moors (1985)
	F(mature)	203	20	
Wawaetorea Island	M	371*	57	Moller & Tilley (1986)
	F	368*	51	
Stewart Island	M	172.4	25	This study
	F	158.6	36	
	both	164.2	61	

* = total length

APPENDIX 6

Mean Foetus Numbers from New Zealand Studies

Ship Rats

Reference	Study Area	Mean Foetus Number
Best 1968	South Island forests	5.85
Daniel 1972	Orongorongo Valley	6.10
Innes 1977	Tiritea Reserve	4.95
This study	Stewart Island	5.86

Kiore

Reference	Study area	Mean Foetus Number
Watson 1956	Little Barrier Island	4.70
Craig & Moller 1978	Tiritiri Matangi Island	7.00
Hitchmough (1980)	Motukawanui Island	4.70
Dick 1985	Kapiti Island	4.66
This study	Stewart Island	4.67

Norway Rats

Reference	Study area	Mean Foetus Number
Beveridge & Daniel 1965	Mokoia Island	8.00
Bettesworth 1972a	Whale Island	6.50
Dick 1985	Kapiti Island	7.52
Moller & Tilley 1986	Bay of Islands	6.90
This study	Stewart Island	6.20

APPENDIX 7

(a) Cochran's Univariate Homogeneity of Variance Test on Diet Categories

Dependent variable	Cochrans C	p
Invertebrate	0.072	0.01
Vertebrate	1.000	< 0.001
Vegetation	0.383	< 0.001
Wood	0.123	< 0.001
Fungus	0.164	< 0.001
Other	0.474	< 0.001

(b) Multivariate Analysis of Variance on Diet Categories

* = $p < 0.05$

** = $p < 0.01$

*** = $p < 0.001$

	Invert	Vert	Veg	Wood	Fungus	Other
	F	F	F	F	F	F
Species	1.679	47.145***	10.593***	1.329	2.482	1.517
Transect	2.037	14.862***	0.880	0.358	0.217	0.400
Season	9.679***	9.953***	12.285***	1.429	1.692	1.031
Weight class	0.349	10.904***	0.521	2.146	0.400	3.201*
Species x transect	4.384***	12.455***	2.204*	1.325	0.651	0.943
Species x season	1.146	8.335***	4.962***	1.917	1.157	1.691
Species x weight class	1.017	7.291***	0.751	2.137*	1.018	2.889**

APPENDIX 8

List of the 49 Diet Items used to describe species differences in diet by Chi-square homogeneity test

Fruit
Cyathodes empetrifolia
Cyathodes juniperina
Dacrydium cupressinum
Halocarpus biformis
Lepidothamnus intermedius
Prumnopitys ferruginea
Other fruit
Seed
Dacrydium cupressinum
Lepidothamnus intermedius
Other seed
Leaf
Cyathodes juniperina
Dacrydium cupressinum
Gahnia procera
Lepidothamnus intermedius
Korthalsella salicornioides
Leptospermum scoparium
Luzuriaga parviflora
Other leaf
Unidentified leaf
Moss
Cyathophorum bulbosum
Other moss
Other plant material
Bark
Blechnum spp. rhizomes
Fern leaves/stems/scales
Liverworts
Unidentified seed/rhizome
Wood
Other plant parts

Invertebrates
Amphipoda
Aquatic invertebrates
Araneida
Blattodea
Carabidae
Other Coleoptea
Coleoptera larvae
Chilopoda
Diptera larvae
Gastropoda (slugs)
Gastropoda (snails)
Lepidoptera larvae
Oligochaeta
Opilione
Orthoptera
Phasmatodea
Unidentified larvae
Other invertebrates
Other Foods
Fungus
Vertebrate
Other items

$\chi^2 = 890.20 \quad \text{d.f} = 96 \quad p < 0.001$

APPENDIX 9

Relative Occurrence of ship rat diet items and Chi-square Homogeneity test

(a) Ho: Occurrence of ship rat diet items did not vary between transects

$\chi^2 = 165.31$ d.f. = 75 $p < 0.001$

	Transect			
Diet item	B	C	D	E
Cyathodes juniperina fruit	1.4	2.5	5.3	1.9
Dacrydium cupressinum fruit	3.0	3.6	2.7	2.5
Prumnopitys ferruginea fruit	5.5	2.1	0.0	4.6
Other fruit	2.7	5.0	5.4	7.9
Seed	1.6	2.8	1.8	2.0
Unidentified seed/rhizome	5.2	4.3	4.5	5.9
Dacrydium cupressinum leaf	3.2	2.5	2.7	0.8
Leptospermum scoparium leaf	1.6	1.8	2.7	1.9
Korthalsella salicornioides	2.7	5.7	6.2	2.4
Other leaf	11.4	13.5	19.6	12.6
Unidentified leaf	1.6	2.1	0.9	2.5
Moss	5.7	2.1	0.9	1.9
Liverwort	2.0	2.8	4.5	1.7
Other plant parts	5.5	4.6	5.4	5.4
Orthoptera	10.0	14.0	12.5	10.3
Araneida	4.3	1.1	0.0	3.2
Opilione	3.9	3.6	0.9	3.7
Phasmatodea	0.7	5.7	3.6	1.0
Coleoptera	4.8	3.2	0.9	6.6
Lepidoptera larvae	3.0	1.1	0.9	3.7
Other larvae	3.6	1.8	0.0	2.2
Chilopoda	3.6	1.8	0.9	3.7
Other invertebrates	5.0	5.0	8.9	7.1
Vertebrate	0.9	2.1	0.0	0.5
Wood and bark	3.9	2.8	5.4	1.3
Other food	3.4	2.1	3.6	2.7

APPENDIX 9 continued.

(b) Ho: Occurrence of ship rat diet items did not vary between seasons

$\chi^2 = 234.94$ d.f. = 75 $p < 0.001$

	Season			
Diet item	A	W	Sp	Su
Cyathodes juniperina fruit	0.6	2.3	1.8	2.8
Dacrydium cupressinum fruit	4.0	4.4	0.4	0.4
Prumnopitys ferruginea fruit	4.0	5.5	3.3	0.4
Other fruit	13.0	6.2	2.6	1.6
Seed	7.3	1.5	1.5	0.4
Unidentified seed/rhizome	3.4	5.6	5.9	4.9
Dacrydium cupressinum leaf	1.1	3.0	1.1	0.8
Leptospermum scoparium leaf	1.1	2.1	1.8	1.6
Korthalsella salicornioides	1.1	5.1	1.8	2.0
Other leaf	5.1	12.1	17.2	16.6
Unidentified leaf	1.1	1.5	4.0	2.0
Moss	1.7	2.5	2.2	6.5
Liverwort	0.6	2.6	2.9	1.6
Other plant parts	3.4	3.4	8.1	8.9
Orthoptera	11.3	11.1	12.5	9.7
Araneida	5.6	1.8	2.2	4.9
Opilione	4.0	3.6	2.6	4.0
Phasmatodea	1.1	2.5	1.5	2.0
Coleoptera	5.6	4.3	3.3	8.1
Lepidoptera larvae	6.2	2.1	1.5	3.6
Other larvae	4.0	2.3	1.5	2.4
Chilopoda	4.0	3.2	2.9	2.4
Other invertebrates	4.5	4.7	11.7	5.7
Vertebrate	1.1	1.4	0.0	0.4
Wood and bark	1.1	2.6	4.4	2.4
Other food	4.0	2.9	1.5	3.6

APPENDIX 9 continued.

(c) Ho: Occurrence of ship rat diet items did not vary between weight class

$\chi^2 = 234.94$ d.f. = 75 $p < 0.001$

	Weight class			
Diet item	1	2	3	4
Cyathodes juniperina fruit	1.3	3.2	3.1	0.9
Dacrydium cupressinum fruit	2.8	2.5	3.1	3.1
Prumnopitys ferruginea fruit	5.0	3.2	3.7	3.4
Other fruit	6.3	6.1	3.4	6.3
Seed	2.2	1.8	2.3	2.1
Unidentified seed/rhizome	4.1	4.6	6.0	5.8
Dacrydium cupressinum leaf	1.6	3.2	1.0	2.6
Leptospermum scoparium leaf	2.5	1.4	1.6	1.3
Korthalsella salicornioides	2.8	3.2	4.2	3.1
Other leaf	15.6	15.7	13.8	8.1
Unidentified leaf	0.0	2.9	3.7	1.8
Moss	4.9	2.1	3.7	2.1
Liverwort	2.5	1.8	2.3	1.6
Other plant parts	5.3	6.8	6.3	3.7
Orthoptera	11.9	11.8	12.0	8.7
Araneida	1.3	3.6	1.3	5.2
Opilione	2.8	2.1	4.4	4.2
Phasmatodea	2.2	2.5	2.6	0.5
Coleoptera	3.8	2.9	4.7	8.1
Lepidoptera larvae	3.1	2.1	2.3	3.1
Other larvae	1.6	1.9	2.1	3.9
Chilopoda	2.8	2.5	2.3	4.5
Other invertebrates	7.2	6.4	4.4	7.9
Vertebrate	0.9	0.7	0.8	0.8
Wood and bark	4.1	2.5	2.1	2.4
Other food	1.9	2.5	2.6	4.5

APPENDIX 10

Relative Occurrence of Norway rat diet items and Chi-square Homogeneity test

(a) Ho: Occurrence of diet items did not differ between transects.

$\chi^2 = 35.08$ d.f = 14 $p = 0.001$

	Transect		
Diet item	B	C	E
Leaf	31.5	27.3	23.9
Fruit	19.9	4.5	14.2
Orthoptera	2.7	11.4	9.7
Opilione	6.8	6.8	8.0
Coleoptera	6.2	0.0	12.4
Aquatic invertebrates	17.8	15.9	6.2
Other invertebrates	8.9	18.2	11.5
Other food	6.2	15.9	14.2

(b) Ho: Occurrence of diet items did not vary with season.

$\chi^2 = 77.41$ d.f = 21 $p < 0.001$

	Season			
Diet item	A	W	Sp	Su
Leaf	36.3	28.8	23.1	20.8
Fruit	17.6	26.0	2.6	4.2
Orthoptera	5.5	2.9	7.7	12.5
Opilione	7.7	6.7	2.6	9.7
Coleoptera	5.5	1.0	0.0	3.6
Aquatic invertebrates	9.9	14.4	23.1	9.7
Other invertebrates	7.7	9.6	20.5	12.5
Other food	9.9	10.6	20.5	6.9

APPENDIX 11

Relative Occurrence of kiore diet items and Chi-square Homogeneity test

Ho: Occurrence of kiore diet items did not vary with season.

$\chi^2 = 109.30$ d.f = 45 $p < 0.001$

	Season			
Diet item	A	W	Sp	Su
Leaf	8.3	14.9	13.8	11.4
Fruit	17.5	5.9	3.3	4.2
Seed	10.0	2.7	1.7	0.8
Unidentified seed/rhizome	4.2	5.4	3.9	3.8
Other plant parts	1.7	5.0	3.3	4.9
Orthoptera	12.5	10.7	12.7	14.4
Araneida	10.0	10.3	8.8	8.3
Opilione	5.8	4.8	3.3	6.4
Oligochaeta	3.3	5.6	8.3	5.3
Amphipoda	0.0	4.4	6.1	2.7
Carabidae	3.3	2.1	5.5	6.8
Other Coleoptera	2.5	3.3	3.9	3.4
Chilopoda	4.2	6.5	8.3	3.4
Invertebrate larvae	5.0	2.5	5.0	6.8
Other invertebrates	7.5	7.7	6.6	10.2
Other food	4.2	8.2	5.5	7.2