SEASONAL DIET OF THE SHIP RAT (*RATTUS R. RATTUS*) IN LOWLAND FOREST IN NEW ZEALAND

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SUMMARY: The seasonal diet of ship rats in a stand of lowland podocarp-rata-broadleaf forest in North Island, New Zealand, was studied from analysis of 173 stomachs, 46 fresh droppings and 10 feeding trials. Arthropods, particularly tree wetas (Order Orthoptera), were the main foods in spring and summer, while drupes, berries and nuts predominated in autumn and winter. Birds were not an important food. Seasonal variations in the diet were related to the seasonal abundance of these foods in the forest.

INTRODUCTION

The European ship, roof or black rat (*Rattus r. rattus* L.) is one of three species of rats introduced and now established in New Zealand. The others are the Norway rat (*Rattus n. norvegicus* Berk.) and the Polynesian rat or kiore (*Rattus e. exulans* Peale). Ship rats probably arrived in New Zealand in the late eighteenth and early nineteenth centuries and are now widespread in towns and forests (Dieffenbach 1843, White 1895, Wodzicki 1950, Watson 1953).

Apart from several short notes published in the late 1800s in which the species of rat mentioned is often open to doubt (e.g. Wilson 1878, Kingsley 1895, Buller 1871), and general surveys (Wodzicki 1950, Watson 1953, 1959), the only recent papers on the ecology and spread of the ship rat in New Zealand are those by Best (1969), Daniel (1972) and Atkinson (in press).

Buller (1873), Stead (1936), Thomson (1922) and others have suggested that ship and Norway rats are at least partly responsible for the marked reduction in numbers of species and abundance of endemic birds. Recently ship rats irrupted on Big South Cape Island, off Stewart Island, and exterminated four species or subspecies of rare birds on the island (Blackburn 1965, Merton 1965), as well as probably exterminating the southern short-tailed bat (*Mystacina tuberculata robusta*) (Messrs D. V. Merton and J. McIntosh, pers. comm.). However, Best (1969) found that birds were not an important food of ship rats in long established rat populations in two South Island forests. Rats may affect the distribution and abundance of geckos and skinks (Whitaker 1968) and possibly of tuatara (*Sphenodon punctatus*) on islands, and of land snails (*Paryphanta* and *Placostylus* spp.), native frogs (*Leiopelma* spp.) and rare endemic arthropods such as the giant ground weta (*Deinacrida* spp.) (Buller 1870).

Beveridge (1964) also found that ship rats can consume almost the entire seed crop of podocarp trees such as rimu (*Dacrydium cupressinum*), matai (*Podocarpus spicatus*) and kahikatea (*P. dacrydioides*) and of hardwood species such as hinau (*Elaeocarpus dentatus*). Ring-barking of young *Pinus radiata* by ship rats has been reported in Chile (Rühm 1966)—but not so far in New Zealand, although podocarp and other timber tree seedlings are destroyed by Norway rats (Beveridge and Daniel 1965).

This paper describing the seasonal foods of ship rats in indigenous forest is part of a long-term study of rodent populations and their food supply in lowland podocarp-rata-broadleaf forest in the Orongorongo Valley. Population dynamics, home range and reproduction have been described (Daniel 1972).

THE STUDY AREA

The study area covered about 16 ha of forest near the DSIR Field Station (41°21′S, 174°58′E) in the Orongorongo Valley, Wellington province. The locality and forest vegetation have been described (Daniel 1972). Briefly, the forest consists of three main strata: a discontinuous upper stratum of emergent northern rata (*Metrosideros robusta)* and podocarps (mainly rimu, matai and miro (*P. ferrugineus*) varying in height from about 25m to over 35m; a discontinuous middle stratum at about 12m to 24m consisting of several species of broadleaf trees—mainly hinau, pukatea (*Laurelia novaezelandiae*) and rewarewa (*Knightia excelsa*); and a continuous lower stratum from about 3m to 12m composed of small trees and shrubs. Epiphytes, particularly *Astelia solandri, Collospermum hastatum* and *Freycinetia banksii,* lianes such as *Ripogonum scandens, Metrosideros fulgens* and *Muehlenbeckia australis,* and five species of tree ferns are conspicuous features of this forest.

Mean annual rainfall at the Field Station over an eight year period, 1953-1960, was 2443mm range 2032 - 2743mm). Mean summer and winter temperatures over the four years 1966-69 were 15.5°C and 6.7°C respectively. Mean winter minimum was 2.8°C and mean summer maximum was 19.4°C. Prevailing westerly winds create turbulent conditions on the valley floor, and on the exposed ridges gusts in excess of 160 km/hr (100 mph) are frequent.

METHODS

1. *Collection of Rats*

The total sample of 173 rats comprised 31 snap-trapped on three lines from November 1966 to October 1967, 125 rats snap-trapped on and around the live-trapping study area from August 1968 to July 1969 and 17 rats killed during live-trapping studies (see Daniel 1972).

2. *Stomach and Faecal Analysis*

Stomachs were removed from freshly killed rats and preserved in 90% alcohol. For analysis the contents were placed in a petri dish and examined under a dissecting microscope. Fifty-three stomachs out of a total of 173 (31%) contained unidentified amorphous starchy material probably representing kernels of hinau, miro or nikau (*Rhopalostylis sapida*) nuts. Many food items could be readily identified, e.g. the speckled femurs of tree wetas (*Hemideina thoracica*), the spotted endocarp of supplejack (*Ripogonum scandens*) berries and the green exocarp of hinau drupes. Plant material was identified by comparing the colour, texture and thickness of exocarp, pericarp and endocarp fragments with a reference collection of ripe and unripe berries, drupes, seeds and nuts from the study area. For arthropods, fragments of antennae, legs and exoskeletal material were compared with those of a reference collection of arthropods. Unidentified fragments were preserved in 90% alcohol for later determination by experts.

Three methods were used to quantify stomach contents:

(1) Items were recorded as present or absent in each stomach and the percentage frequency of occurrence was calculated (the number of stomachs in which an item occurred expressed as a percentage of the total number of stomachs examined).

(2) The number of occurrences of each food item was expressed as a percentage of the total of occurrences of all items, following Hynes (1950) and Rudge (1968).

(3) A visual estimate to the nearest 10% was made of the relative volumes occupied by plant and animal matter in the contents of each stomach.

Hansson (1970) discussed the usefulness and limitations of these three methods. No attempt was made to weigh the stomachs or food items as done by Kami (1966) and Fall, Medina and Jackson (1971).

To supplement the stomach analyses, 46 fresh droppings were collected during live-trapping from the traps and from live animals: 12 in spring (September to November), 10 in summer (December to February), 12 in autumn (March to May) and 12 in winter (June to August). The droppings for each season were grouped, mixed with water in a petri dish and examined under a dissecting microscope. Although more finely comminuted than many of the stomach samples, the contents of the droppings gave a rough indication of the seasonal frequency of plant and insect foods, and some plants and insects could be identified from small fragments. The seasonal changes in plant and animal foods followed the same trends as those from stomach contents.

TABLE 1. *Analysis of 173 ship rat stomachs showing number of occurrences of each food item, its percentage frequency of occurrence and contribution to the diet.*

	SPRING			SUMMER			AUTUMN			WINTER			ALL SEASONS		
	No.	% Occurrence	% Diet	No.	% Occurrence	% Diet	No.	% Occurrence	% Diet	No.	% Occurrence	% Diet	No.	% Occurrence	% Diet
PLANT MATTER															
Unid. pericarp	10	24	16	3	7	4	24	55	36	16	43	30	53	32	20
Elaeocarpus dentatus	0	0	0	0	0	0	2	5	3	7	19	13	9	5	3
Hedycarya arborea	2	5	3	7	16	9	1	2	1	3	8	6	13	8	5
Rhipogonum scandens	3	7	5	0	0	0	6	14	9	5	14	9	14	8	5
Rhopalostylis sapida	0	0	0	0	0	0	2	5	3	1	3	2	3	2	1
Coprosma spp.	0	0	0	0	0	0	0	0	0	2	5	4	2	1	1
Schefflera digitata	1	2	2	0	0	0	0	0	0	1	3	2	2	1	1
Corynocarpus laevigatus	0	0	0	1	2	1	0	0	0	0	0	0	1	1	1
Macropiper excelsum	0	0	0	3	7	4	8	18	12	2	5	4	13	8	5
Green leaves*	11	27	18	10	22	13	4	9	6	2	5	4	27	16	10
Fungi	0	0	0	0	0	0	0	0	0	4	11	7	4	2	2
STOMACHS WITH PLANT MATTER	27	64	—	24	51	—	40	89	—	34	87	—	125	72	—
ANIMAL MATTER															
Unid. Arthropods	4	10	7	6	13	8	4	9	6	1	3	2	15	9	6
Orthoptera															
Hemideina thoracica	22	54	36	25	56	33	15	34	22	5	14	9	67	40	26
Unid. Orthoptera	0	0	0	0	0	0	1	2	1	0	0	0	1	1	1
Lepidoptera															
adults	1	2	2	1	2	1	0	0	0	0	0	0	2	1	1
larvae	2	5	3	0	0	0	0	0	0	2	5	4	4	2	2
Phasmatodea															
Phasmatoda	2	5	3	2	4	3	0	0	0	1	3	2	5	3	2
Coleoptera	2	2	3	5	11	7	0	0	0	0	0	0	7	4	3
Hemiptera															
Cicadellidae	0	0	0	8	18	11	0	0	0	0	0	0	8	5	3
Diptera															
pupae	0	0	0	2	4	3	0	0	0	1	3	2	3	2	1
Araneae															
Araneidae	0	0	0	0	0	0	0	0	0	1	3	2	1	1	1
Hymenoptera															
Formicidae	1	2	2	0	0	0	0	0	0	0	0	0	1	1	1
Mollusca															
Wainuia urnula	0	0	0	2	4	3	0	0	0	0	0	0	2	1	1
Aves															
Unid. feathers	0	0	0	1	2	1	0	0	0	0	0	0	1	1	1
STOMACHS WITH ANIMAL MATTER	28	67	—	37	79	—	18	40	—	9	23	—	92	53	—
Rattus hair	0	0	—	2	4	—	0	0	—	2	5	—	4	2	—
Bait	8	19	—	8	18	—	6	14	—	4	11	—	26	16	—
Empty	1	—	—	2	—	—	1	—	—	2	—	—	6	—	—
Total occurrences**	61			76			67			54			259		
Total examined	42			47			45			39			173		

* If these are the crop contents of wetas, the % occurrence and % of diet for plant foods will be over-estimated and those of animal foods under-estimated.

** Excludes hair, bait and empty stomachs. Empty stomachs are not included in percentage frequency of occurrence calculations.

3. *Feeding Trials*

Ten multiple-choice feeding trials were conducted to supplement the stomach and faecal analyses; seven trials were with plants (including one with five species of fungi) and three with animals foods (including arthropods, molluscs and a dead mouse).

A different rat, live-trapped on the study area, was used for each of the ten trials and released where caught after the two-day feeding trial. The trials were carried out in a 35 × 15 × 13cm cage. A wood-wool nest was provided at the back of the trap, water was available *ad libitum* and the foods being tested were placed on a single petri dish at the front of the cage, which was covered with a cloth to minimise disturbance. All remaining food fragments were examined after each trial.

RESULTS

1. *Diet of the Ship Rat*

The seasonal and average composition of the diet is shown in Table 1. The average frequency of occurrence of plant and animal foods was 72% and 53% respectively. The most frequent single item of plant food was unidentified, finely comminuted pericarp or endosperm material, which scored 20%. This probably comprised kernels or endosperm of hinau, miro or nikau palm nuts of which no recognisable exocarp or mesocarp fragments are ingested by the rat; the nuts are chewed through at one end and the kernels extracted and eaten (Fig. 1). The next most frequent item was green leaf material at 10%. This is believed not to represent green leaves eaten by rats but rather the extremely finely chewed leaves from the crops of tree wetas. All the stomachs containing leaves also contained recognisable fragments of tree weta. Pigeonwood *(Hedycarya arborea)*, supplejack, kawakawa (*Macropiper excelsum*) and hinau were present in amounts varying from 5% to 3% of the total diet (see Tables 4 and 5 for scientific names of identified foods).

Of animal matter, tree wetas were particularly prominent at 26%, followed by unidentified arthropods at 6%, cicadas 3%, Coleoptera 3% and stick insects 2%. Bird feathers occurred in only one of the stomachs. Rat hair was present in four stomachs, probably ingested during grooming. No traces of bird bones, egg shells, rat or mouse flesh or bones were found although reported by Best (1969). Slugs were not found although Best (1969) recorded a 20% frequency of occurrence for them. No annelids were found.

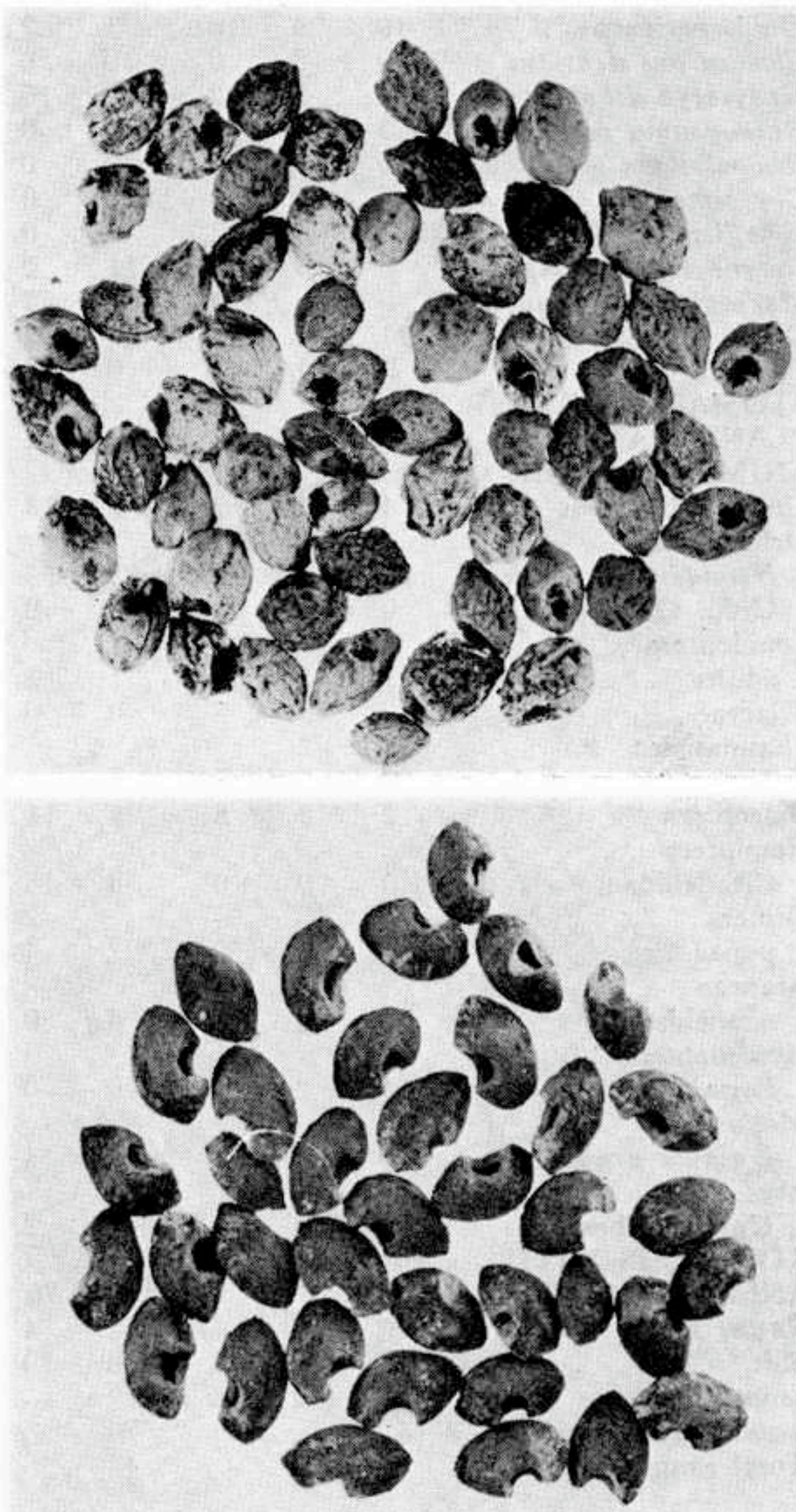

FIGURE 1. *Hinau nuts* (Elaeocarpus dentatus) *(upper photo) and miro nuts* (Podocarpus ferrugineus) (*lower photo*) *gnawed open by ship rats and the kernels extracted.*

2. *Seasonal Variation in Diet*

Marked seasonal variations in the diet are shown in Table 1. Frequency of occurrence of plant matter varied from 64% to 57% in spring and summer (figures probably over-estimated by weta crop contents) to 89% and 87% in autumn and winter. The estimated percentage volumes of plant foods were 23% and 16% for spring and summer and 62% and 89% in autumn and winter (Table 2). The various plant foods were eaten as they ripened, e.g. hinau and nikau palm in autumn and winter, pigeonwood in all four seasons, karaka (*Corynocarpus laevigatus*) in autumn and fungi in winter.

TABLE 2. *Percentage volumes of plant and animal foods in 173 ship rat stomachs, estimated by eye.*

	Plant foods (%)	Animal foods (%)
SPRING (n = 42)	23	77
SUMMER (n = 47)	16	84
AUTUMN (n = 45)	62	38
WINTER (n = 39)	89	11

Animal foods also showed marked seasonal changes. Orthoptera (tree wetas), the dominant arthropod food, comprised 36% and 33% of the animals recorded in the stomachs in spring and summer, declining to 22% and 9% in autumn and winter. Of the minor animal foods, Hemiptera (cicadas) reached 11% of the animals recorded in summer, with Coleoptera, Diptera pupae, adult Lepidoptera, Phasmatoda (stick insects), Mollusca and birds ranging from 1% to 7% in spring and summer. In autumn and winter, Lepidoptera larvae, Phasmatoda, Diptera pupae and Araneae (spiders) made up only 2% to 4% of the total animals identified.

3. *Number of Food Items per Stomach*

The mean number of food items per stomach ranged from 1.3 in spring to 1.5 in summer, autumn and winter; but the lower mean in spring is not statistically significant. The annual mean of 1.4 species per stomach is lower than the 1.9 found by Best (1969) in mixed podocarp forest in Westland and much lower than the 2.7 he recorded in a different forest type on Banks Peninsula.

4. *Feeding Trials*

The results of seven feeding trials on selected plant foods (Table 3) show both the wide range of plants eaten by ship rats in the Orongorongo forest and the particular parts favoured by them. Table 3 also gives the results of three feeding trials on selected animal foods.

5. *Other Evidence of Feeding Habits*

Notes were kept of foods in the study area that showed signs of having been gnawed and eaten by rats. These included many rat-opened hinau and miro nuts under fruiting trees. For example, of 1700 hinau and 600 miro nuts examined between May 1970 and February 1971, 359 (21%) of the hinau and 117 (19%) of the miro nuts had been eaten (see Fig. 1). Other nuts and seeds found gnawed by rats include those of rimu, kahikatea, matai and nikau palm. Gnawed fruits of kiekie (*Freycinetia banksii*), karaka (*Corynocarpus laevigatus*), poroporo (*Solanum aviculare*) and *Astelia solandri*, fungi (particularly *Weraroa erythrocephala*) and native land snails (*Wainuia urnula*) with the shells eaten round the spiral and the snails extracted, were frequently observed. Other native snail shells characteristically smashed by thrushes (see Morris 1954) were also found on the forest floor. Several of the fruits and berries eaten by rats are also favoured by opossums (*Trichosurus vulpecula)*, particularly the fleshy mesocarp of hinau, karaka and pigeonwood fruits, and horopito (*Pseudowintera axillaris*) and passion flower (*Tetrapathaea tetranda*) fruits (Dr B. D. Bell, pers. comm.; see also Mason 1958).

The remains of adult and nymphal cicadas were also observed beside both ground and tree traps visited by rats the previous night. Checklists of all plant and animal foods known to be eaten by ship rats in the Orongorongo Valley are given in Tables 4 and 5. Although incomplete, these lists demonstrate the wide variety of foods eaten in this mixed forest habitat.

TABLE 3. *Results of ship rat feeding trials on selected plant and animal foods.*

Trial Number	Food Presented	Number	Results
1	Ripe *Elaeocarpus dentatus* drupes	2	Exocarp and mesocarp chewed
	Elaeocarpus dentatus nuts	2	Opened and kernels eaten
	Ripe *Podocarpus ferrugineus* drupes	2	Not touched
	P. ferrugineus nuts	2	One opened and kernel eaten
	Ripe *Rhopalostylis sapida* drupes	2	Exocarp and mesocarp chewed
	R. sapida nuts	2	Opened and kernels eaten
2	Ripe *Hedycarya arborea* drupes	2	Exocarp and endocarp chewed
	H. arborea nuts	2	Not touched
	Ripe *Rhipogonum scandens* berry	2	Exocarp and endocarp chewed
	R. scandens seeds	2	Both eaten
	Ripe *Macropiper excelsum* berries	2	One eaten, other partly eaten
	Ripe *Pseudowintera axillaris* berries	2	Both eaten, but seeds untouched
3	Ripe *Schefflera digitata* drupes	6	All eaten except for seeds
	Ripe *Coprosma australis* drupes	6	All eaten except for three seeds
	Ripe *C. robusta* drupes	6	All eaten except for seeds
	Ripe *C. lucida* drupes	6	All eaten except for one seed
	Ripe *Astelia solandri* fruits	6	All eaten
	Ripe *Collospermum hastatum* fruits	6	All eaten except for some exocarp
4	Ripe *Corynocarpus laevigatus* drupes	2	Exocarp and mesocarp chewed
	C. laevigatus nuts	2	Not touched
	Ripe *Freycinetia banksii* fruit	1	Half eaten, mesocarp and seeds
	Ripe *Tetrapathaea tetranda* fruits	2	Seeds eaten, exocarp left
	Ripe *Solanum aviculare* berries	2	Exocarp and mesocarp chewed
	Nothofagus truncata seed	10	Eight eaten, exocarp left
5	*Pseudopanax arboreum* leaves	2	Both nibbled on margins
	Schefflera digitata leaves	2	Not touched
	Melicytus ramiflorus berries	6	Four eaten, two not touched
6	*C. australis* leaves	2	Not touched
	C. lucida leaves	2	Not touched
	Metrosideros robusta leaves	2	Not touched
7	*Weraroa erythrocephala*	1	Parts of pileus and stipe eaten
	Weraroa virescens	1	Parts of pileus and stipe eaten
	Thaxterogaster porphyrium	1	Parts of pileus and stipe eaten
	Aseroe rubra	1	Not touched
	Clathrus cibarius	1	Small part eaten
8	*Prionoplus reticularis*	2	Body and legs eaten
	Hemideina thoracica	2	Body and legs eaten
	Amphipsalta zelandica or *A. cingulata*	2	Body, legs and one head eaten
9	*Clitarchus* sp.	2	Abdomen eaten
	Odontria magnum	2	Abdomen eaten
	Chlorochiton suturalis	2	Abdomen eaten
10	*Aenatus viriscens*	2	Abdomen eaten
	Wainuia urnula	2	Shells opened at spiral and snails eaten
	Mus musculus	1	Not touched

6. *Stomach Parasites*

Stomach nematodes varying in size from about 5-65mm at times comprised as much as 90% by volume of the stomach contents. The maximum number found in any one stomach was 26. All nematodes were preserved but only one species was present, *Mastophora* (*Protospirura*) *muris* (Dr L. K. Whitten, in litt., 1970). The mean numbers for the four seasons from spring to winter were 5.2, 3.2, 2.8 and 2.5 respectively, but the differences between them are not statistically significant. The highest levels of parasitism occurring in spring and summer coincided with the highest proportions of tree wetas in the diet. Lim (1970) in Malaya found that species of rats with a predominantly insectivorous diet had much higher numbers of stomach nematodes than those eating a vegetable diet. The high levels of parasitism in the present study may similarly reflect the large numbers of insects in the diet.

DISCUSSION

The basic diet of berries, seeds, nuts and arthropods of *Rattus r. rattus* in this North Island forest is similar to that found by Best (1969) in two South Island forests, by Kami (1966) in Hawaii, by Fall, Medina and Jackson (1971) on the Marshall Islands and by Harrison (1954, 1961) for two subspecies of *R. rattus* in Malaya.

The seasonal variation in the composition of the diet is also similar to that found by Best (1969). Hansson (1971) in Sweden found that three species of rodents ate most seeds in autumn-winter

TABLE 4. *Checklist of plants eaten by ship rats in the Orongorongo Valley, with details of parts eaten.*

Scientific name	Common name	Parts eaten
MONOCOTYLEDONS		
Astelia solandri	Perching lily	Succulent berry and seeds
Collospermum hastatum	Perching lily	Succulent berry and seeds
Freycinetia banksii	Kiekie	Mesocarp and seeds
Rhopalostylis sapida	Nikau palm	Exocarp, mesocarp and kernel
Rhipogonum scandens	Supplejack	Exocarp, mesocarp and endocarp
DICOTYLEDONS		
Coprosma australis	Raurekau	Succulent drupe and some seed
C. robusta	Karamu	Succulent drupe and some seed
C. lucida	Karamu	Succulent drupe and some seed
Elaeocarpus dentatus	Hinau	Exocarp, mesocarp and kernel
Hedycarya arborea	Pigeonwood	Exocarp and mesocarp only
Macropiper excelsum	Kawakawa	Mesocarp and seeds
Nothofagus truncata	Hard beech	Endocarp only
Schefflera digitata	Pate	Exocarp and mesocarp only
Corynocarpus laevigatus	Karaka	Exocarp and mesocarp only
Tetrapathaea tetranda	Passion flower	Seeds
Pseudowintera axillaris	Horopito	Succulent berry not seeds
Solanum aviculare	Poroporo	Exocarp and mesocarp
Melicytus ramiflorus	Mahoe	Succulent berry and seeds
GYMNOSPERMS		
Dacrydium cupressinum	Rimu	Endosperm and receptacle
Podocarpus dacrydioides	Kahikatea	Endosperm and peduncle
P. spicatus	Matai	Endosperm
P. ferrugineus	Miro	Endosperm
FUNGI		
Weraroa erythrocephala	Red tobacco pouch fungus	Pileus and stipe
Weraroa virescens	Pale blue tobacco fungus	Pileus and stipe
Thaxterogaster porphyrium	Violet tobacco pouch	Pileus and stipe
Clathrus cibarius	Basket fungus	Part of fungus eaten

TABLE 5. *Checklist of animal foods eaten by ship rats in the Orongorongo Valley with details of the parts eaten.*

Name	Part eaten
ARTHROPODS	
Order Orthoptera	
Hemideina thoracica (Tree weta)	Abdomen and parts of legs
Unidentified ground weta	Abdomen and parts of legs
Order Phasmatodea	
Clitarchus sp.	Abdomen
Unidentified stick insect	Abdomen
Order Hemiptera, sub-order Homoptera	
Amphipsalta zelandica or *A. cingulata* (Adults and nymphs)	Abdomen, thorax, head and legs
Order Coleoptera	
Prionoplus reticularis (Huhu beetle)	Abdomen and legs
Unidentified ground beetle (Family Carabidae)	Abdomen
Chlorochiton suturalis (Green chafer beetle)	Abdomen
Odontria magnum (Scarab beetle)	Abdomen
Order Lepidoptera	
Aenatus virescens (Puriri moth)	Abdomen
Unidentified moth	Abdomen
Unidentified larvae	Whole larva
Order Diptera	
Unidentified pupae	Whole pupa
Order Hymenoptera	
Unidentified ant (Family Formicidae)	Whole ant
Order Araneae	
Unidentified spider	Whole spider
MOLLUSCS	
Class Gastropoda	
Wainuia urnula (Native snail)	Whole snail except shell
AVES	
Unidentified bird	Small feather fragments in stomach

and most animal foods in spring and summer. The present study confirms that ship rats are opportunistic feeders and eat a variety of foods as each becomes abundant in the forest.

Best (1969) found much more green plant matter (about 72%) than was present in the stomachs in the present study. All or most of the green plant matter in the present study was thought to be the crop contents or unexcreted droppings of tree wetas (termed secondary diet by Hansson (1970)). Most of the leaves presented in the feeding trials were not touched, which supports this suggestion. Since Best (1969) found many wetas in the diet (seasonal frequency of occurrence ranged from 17% to 62%), most of his green plant matter may have been of secondary origin.

The dissection of four tree wetas confirmed that both the crop contents and unexcreted droppings retained the green colour of the leaf food material. In addition, the size and consistency of the weta food material were similar to much of the leaf material in the rat stomachs. Nonetheless ship rats may sometimes eat leaves directly. Although neither Kami (1966) nor Harrison (1961) record ship rats eating leaves, apart from grass, in Hawaii and Malaya respectively, ship rats at high density on Big South Cape Island, New Zealand, were observed feeding on many plant foods including leaves; these included the leaves and bark of *Pseudopanax arboreum*, blades of *Poa litorosa*, and the leaves, stems and roots of *Stilbocarpa lyallii* (Mr D. V. Merton, pers. comm.). Similar observations of Norway rats eating the bark and leaves of *Pseudopanax arboreum* were recorded at high density on Mokoia Island, Lake Rotorua (Beveridge and Daniel 1965).

The importance of wetas in the diet of ship rats in the Orongorongo Valley, not only in spring and summer but also in autumn and winter, is of interest because, with one exception, all the wetas identified were tree or bush wetas (*Hemideina thoracica*). No cave wetas were found in the diet, although at least two large species are present in the study area (*Gymnoplectron edwardsii*—head and body length up to 30mm—and *Pachyrhamma longipes*—head and body length up to 37mm). Best (1969) found that cave wetas (Family Rhaphidophoridae) were eaten by rats mainly in autumn and winter and tree wetas (Family Henicidae) mainly in summer and autumn. He concluded from this that there was a seasonal shift in focus of feeding activity from the forest floor to the canopy. The present data suggest that tree wetas are abundant in this mixed forest throughout the year and nocturnal observations show that tree wetas are active on the forest floor as well as in the low and high canopy (Mr M. J. Meads, pers. comm.). Mirams (1957) reported that tree wetas feed extensively on the forest floor in kauri (*Agathis australis*) forests, where they eat large quantities of the fallen kauri seed. Other mammals in the study area known to prey on tree wetas include stoats (*Mustela erminea*) (Dr C. M. King, pers. comm.) and possibly opossums (Mason 1958). A study of the seasonal abundance and distribution of this large orthopteran (♂♂ 5-7 g with head and body length up to 60mm) in mixed forest would be useful in studying the seasonal food habits of mammalian and avian predators.

The effects of ship rats on forest regeneration are difficult to establish. Beveridge (1964) has shown that almost the entire seed crop of important podocarp and hardwood species can be consumed by ship rats and the present study extends the list of seeds and fruits eaten. Atkinson (in press) suggests that changes in the regeneration pattern of some plants may have occurred following the spread of the ship rat; but since the Polynesian rat was present for some 1000 years and is known to have eaten many of the same seeds and forest fruits as ship rats, the effects of ship rats on forest regeneration may have been no greater than were those of the Polynesian rat.

Several species of birds also consume quantities of forest seeds and fruits, but some, like the pigeon (*Hemiphaga novaeseelandiae*), digest only the fleshy mesocarp of fruits such as miro, hinau, nikau and pigeonwood, and defaecate the viable kernels (Beveridge 1964). This behaviour is similar to that of opossums with fruits such as hinau, horopito and pigeonwood. Other birds such as parakeets (*Cyanoramphus* spp.) eat the kernels of beech mast and destroy the seed. The combined effects of rats and birds on the regeneration of forest plants and possible competition between rats and some species of birds for certain plant foods, as mentioned by Atkinson and Campbell (1966), require detailed study.

Birds were not an important part of the diet. This agrees with Best (1969) who further argued that, in forests where ship rats have been present for probably over 100 years, bird numbers are not likely to be further reduced by rats provided the stability of the habitat is not altered and that long established rat populations remain at low density. Although ship rats are not known to have irrupted to plague proportions as did Polynesian rats periodically from 1856-1888, minor irruptions of ship rats still occur, the most recent being in the north of the South Island and southern part of the North Island during 1971-72 concurrently with a mouse (*Mus musculus*) plague (Taylor and Daniel unpubl.). These irruptions followed unusually heavy seedfall of beech, podocarps and hinau. In these irruptive situations bird predation by rats may increase as the supplies of the main plant and arthropod foods become scarce. However, even if bird populations could be shown to have decreased following such a minor rat irruption, it would be difficult to establish whether ship rats or increased numbers of stoats and feral cats were responsible.

It is generally accepted that New Zealand's avifauna was greatly altered during the initial spread of ship and Norway rats, or at some time later (Atkinson in press). However, further local but less severe fluctuations in numbers of certain species of the remaining avifauna will probably occur as populations of ship and Norway rats fluctuate in response to their plant and arthropod food supplies.

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