

**ECOLOGY AND ERADICATION OF NORWAY RATS
ON LANGARA ISLAND, QUEEN CHARLOTTE ISLANDS**

by

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ABSTRACT

Norway rats (*Rattus norvegicus*) were introduced to Langara Island in the Queen Charlotte Islands (Haida Gwaii), British Columbia, and are thought to be an important factor contributing to the decline of Ancient Murrelets (*Synthliboramphus antiquus*) and other seabirds breeding on the island. I studied the diet, distribution and habitat use of Norway rats to provide information for an eradication campaign. Stomach contents and isotopic composition of livers of Norway rats trapped on Langara Island during spring and summer of 1995 indicate that rats near the coast feed primarily on marine invertebrates, fruits and seeds, whereas rats in the interior feed primarily on terrestrial invertebrates and plant shoots. Ancient Murrelets occurred with highest frequency and volume in the diet of rats trapped in the Ancient Murrelet colony.

Capture rates of Norway rats in snap traps at the seabird colony during the breeding season of Ancient Murrelets ranged between 0 and 0.7 captures (C) per 100 trap nights (TN), while concurrent capture rates in regions of the island outside of the seabird colony ranged between 2.2 to 17.1 C/100 TN. This indicates that the presence of breeding seabirds likely reduces the effectiveness of snaptrapping and livetrapping to monitor rats on Langara Island.

The coastal habitat on Langara Island has approximately 3 times the density of rats than the interior of the island. In the interior, rats are more likely to be found in areas with dense salal (*Gaultheria shallon*) and red huckleberry (*Vaccinium parvifolium*) than in areas with sparse shrub cover. This association between Norway rats and dense shrub thickets can be used to refine baiting procedures for the poison campaign.

Norway rats on Langara Island and its associated islands appear to have been eradicated. Rats were not trapped nor observed in the sample areas after the poison campaign in the summer of 1995. Feeding activity by rats was not found on apples, which

serve as sensitive indicator baits, during 48 apple-nights. Rats were detected around the lighthouse and the fishing lodges in January 1996, but since then have not been detected on Langara Island. Measures must be taken to prevent the reintroduction of rats to the island.

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GENERAL INTRODUCTION

Lugo (1988) points out the irony of the introduction of exotic species to oceanic islands. While the total number of species increases locally, it does so often at the expense of endemic species, resulting in a homogenization of the Earth's biota and a net loss of species worldwide. All oceanic islands, e.g., the Hawaiian archipelago, the Galapagos Islands, New Zealand, and the islands surrounding Antarctica, are experiencing this conversion to some degree (Carlquist 1974, Bramwell 1979, Wace 1986, Chapius *et al.* 1994). Approximately 90% of all bird extinctions since contact with Europeans have occurred on islands (Vitousek 1988). These extinctions resulted from loss of habitat, predation, hunting, competition, and disease. Alien predators, introduced intentionally or inadvertently, are the most important cause of extinction of island birds (King 1985, Brown 1989). The most common and widespread of these introduced predators are rats, *Rattus* spp., which have caused 54 percent of extinctions due to introduced predators (Atkinson 1977, Atkinson 1985, King 1984, Diamond 1985, Dobson 1988).

Interactions between introduced rats and seabirds

Three species of rats have been implicated in declines of bird populations: the black or roof rat (*Rattus rattus*), the Norway or brown rat (*R. norvegicus*), and the Polynesian rat (*R. exulans*) (Moors and Atkinson 1984, Diamond 1985). Differences among these rat species, as well as the behaviour and size of the birds involved, determine whether a rat-bird interaction leads to coexistence or decline of the bird population (Atkinson 1985). Imber (1975) concluded that petrels would be endangered by a species of rat whose maximum weight approaches or exceeds that of the bird. *Rattus exulans*, the smallest of the 3 rats, preys on the fewest bird species, although it can kill the Laysan Albatross (*Diomedea immutabilis*), the largest bird preyed on by any rat (Diamond 1985). *Rattus rattus*, intermediate in size between *R. norvegicus* and *R. exulans*, readily climbs

trees and thus typically preys on birds in the canopy. The burrowing habits of *R. norvegicus* makes it a particular threat to burrow- and surface-nesting seabirds (Atkinson 1985). Rats may also have indirect effects on island birds by acting as prey for other seabird predators such as feral cats (*Felis sylvestris*), weasels (*Mustela* spp.), and mongooses (*Herpestes auropunctatus*) (Moors and Atkinson 1984, Diamond 1985, Amarasekare 1994). The rats sustain these predators during non-breeding periods when the birds are at sea. Through direct and indirect effects, introduced rats can significantly reduce the native avifauna of oceanic islands, and thus eradication of rats must often precede other conservation efforts to restore breeding habitat for birds.

Eradication of rats in New Zealand

Wildlife officials in New Zealand have successfully eradicated rats from more than 40 offshore islands, primarily to secure safe habitat for the reintroduction of indigenous birds, reptiles and amphibians (Veitch and Bell 1990, Taylor and Thomas 1993, Towns 1994, Veitch 1994). They have honed a technique that takes advantage of new 'second-generation' anticoagulant poisons, which have potent and highly palatable formulations, and aspects of rat behaviour, such as their preference for feeding on what their conspecifics are eating (Galef *et al.* 1987, Taylor and Thomas 1989, Taylor and Thomas 1993). The technique involves dispensing rodenticides, primarily brodifacoum, from fixed bait stations placed throughout the entire island. Stations are spaced according to observed densities of rats. The successful eradication of rats on islands in New Zealand provide hope that other islands can be similarly restored to support seabird populations.

Rats in the seabird colonies of British Columbia

Introduced predators have affected seabird populations in British Columbia (Bailey and Kaiser 1993). In the Queen Charlotte Islands (Haida Gwaii), the population of Ancient Murrelets (*Synthliboramphus antiquus*) at Dodge Point, Lyell Island, where black

rats were introduced by 1960, decreased by 25% between 1982 and 1992 (Gaston 1994; Bertram and Nagorsen 1995). More dramatically, the avifauna of Langara Island and its associated islands, Cox and Lucy, decreased in both numbers and diversity during the last 40 years. Surveys of Ancient Murrelets indicate the original population of approximately 200,000 breeding pairs (Gaston 1992) decreased to 80,000-90,000 in 1971 (Vermeer *et al.* 1984), to $21,740 \pm 3,570$ (SE) in 1981 (Rodway *et al.* 1983), to $24,000 \pm 6,250$ (SE) in 1988 (Bertram 1989, Bertram 1995), and to $14,630 \pm 2,060$ (SE) in 1993 (Harfenist 1994). The disappearance of breeding populations of Cassin's Auklets (*Ptychoramphus aleuticus*), Rhinoceros Auklets (*Cerorhinca monocerata*), Fork-tailed Storm Petrels (*Oceanodroma furcata*), and Leach's Storm Petrels (*O. leucorhoa*), has accompanied this decline (Rodway *et al.* 1983). A small colony of Tufted Puffins, (*Fratercula cirrhata*), remains on Cox Island (Vermeer *et al.* 1984, Campbell *et al.* 1990), and Pigeon Guillemots (*Cephus columba*) continue to breed on a large boulder with strongly recurved sides on the south part of Langara Island (Bailey and Kaiser 1993).

Recent investigations have implicated predation by Norway rats on adults, chicks and eggs as a major cause in the decline of breeding Ancient Murrelets on Langara Island (Bertram 1989, Taylor 1993, Harfenist 1994, Bertram 1995). Bertram (1995) found dead adult Ancient Murrelets with wounds to their napes, typical of rat predation on seabirds (Moller 1983). Furthermore, murrelet bones were found in almost 30% of breeding murrelet burrows. Skeletal remains were most common in abandoned areas of the seabird colony and were least common in areas where burrows were occupied (Bertram 1995). Previous researchers dismissed the importance of rats in the decline of the Ancient Murrelets, and focused instead on reduced food supply due to commercial fishing in adjacent waters, avian predators and unknown causes, citing that rats had been present long before the observed decline (Nelson and Myres 1976, Sealy 1976). However, the Norway rat has recently replaced the black rat previously found on Langara Island (Taylor

1993, Bertram 1995, Bertram and Nagorsen 1995). Because of its large size and burrowing habits, the Norway rat is a greater threat to breeding seabirds than the black rat (Moors and Atkinson 1984). Furthermore, the arrival of the Norway rat coincides with the extinctions of the seabird colonies and also with the apparent disappearance of the deer mouse (*Peromyscus maniculatus*) (Taylor 1993).

The Langara Island Seabird Habitat Restoration Project

Funds to restore breeding habitat for seabirds on Haida Gwaii became available in 1992 from the litigation settlement of the Nestucca oil spill. This settlement specifically mentioned eradication of rats from Langara Island as an important method for ensuring the long-term survival of seabirds in Haida Gwaii (Harfenist 1994).

Accordingly, Environment Canada established the Langara Island Seabird Habitat Recovery Project (LISHRP) which planned to eradicate the Norway rats from Langara Island and its associated islands in five distinct phases: feasibility studies and environmental review in 1993, pilot tests and site preparation in 1994, eradication in 1995, monitoring through 1996 and 1997, and finally clean-up and removal of the bait stations (Kaiser *et al.* in prep.). Lucy Island became the site of the pilot test in 1994. The eradication on Langara Island was attempted during July and August 1995. Taylor (1993) and Kaiser *et al.* (in prep.) describe techniques in detail and only a brief summary is presented here.

Beginning in May 1995, 6 weeks before eradication commenced, crews on Langara Island placed an individually-marked PVC bait station, measuring 0.5 m in length and 0.1 m in diameter, at every 100 m on a grid over the entire island (1 station per ha). Within 100 m from the coast, density of bait stations was increased to 1 at every 75 m to accommodate for high densities of rats. A spacing of 1 station per ha ensured that each rat received at least 1 bait station within its home range (Innes and Skipworth 1983,

Hickson *et al.* 1986, Moors 1985b, Taylor and Thomas 1993). On July 9, 1995, the bait stations were loaded with 20-g blue wax blocks which contained tallow, castor sugar, blood, bone and 50-ppm brodifacoum as the active ingredient. Brodifacoum acts by blocking the oxidation-reduction cycle of vitamin K1 in the liver, thus preventing the production of blood clotting proteins (Lund 1988). This formulation is registered in Canada as RATAK+ Weatherblock, supplied by ZENECA Agro, and used specifically for clearing rats from seabird colonies. Operators monitored the bait stations every 48 h and replaced missing baits to maintain a constant number of 12 baits per station near the coast and 6 per station inland. Ninety-five percent of the bait was taken by July 26 (Day 17), although stations continued to be visited by rats until August 9 (Day 26). In mid-August 1995, crews placed 4 baits in a plastic bag in each bait station near the coast and 2 baits similarly bagged in each bait station in the interior. These will be left on the island for 2 years until 1997, when a clean-up will remove the bait stations and the remaining bait.

Cox Island was treated similarly, although the bait was dispensed primarily out of hoppers. These hoppers were modified bait stations that could carry up to 30 baits stacked vertically and threaded onto a 1-m steel rod which pinned the station to the ground. These stations were checked weekly. Lucy Island was first treated in the summer of 1994 during the pilot test during which 42 bait stations were spaced 100 m apart along 3 separate lines and checked every 24 h (Buck 1995). The same stations were used during the summer of 1995 for a second treatment.

Objectives

Most studies of free-living Norway rats have focused on commensal populations in cities or agricultural settings (Calhoun 1962). Studies of Norway rats living totally without human support have largely come from New Zealand (Beveridge and Daniel 1965, Bettesworth and Anderson 1972, Moller and Tilley 1984, Moors 1985b), and

islands in the Antarctic (Pye and Bonner 1980) and near the continental United States (Lattanzio and Chapman 1980). I studied the ecology and eradication of Norway rats on Langara Island, based primarily on data gathered during 1 large scale snaptrapping program and 2 separate livetrapping programs that occurred in conjunction with the poisoning campaign. I described the diet of Norway rats using stomach content analyses and stable isotope composition of liver tissue of rats (Chapter 1). I examined methods to monitor the presence and density of Norway rats (Chapter 2), and described their distribution and habitat use (Chapter 3). In Chapter 4, I assessed the efficacy of the eradication campaign. I also examined the utility of 2 modifications to the bait stations for their ability to exclude shrews (Chapter 5).

STUDY AREA

I conducted my study on a group of islands near the northwest tip of the Queen Charlotte Islands, British Columbia (54°12'N, 133°01'W). This group is known as Kiisgwaii and consists of Langara Island (3253 ha), Lucy Island (42 ha), Cox Island (8 ha), and a few small islets and rocks (Fig. 1). All lie in the Coastal Western Hemlock biogeoclimatic zone, central very wet hypermaritime variant (CWHvh2), characterized by a cool climate, very little snowfall, and fog, cloud, and drizzle common throughout the year (Green and Klinka 1994).

Langara Island is relatively flat, with cobble and sand beaches on the east and south sides and steep cliffs to the north and west. It also has several small inland lakes and permanent streams. The island has 4 major forest habitat types in concentric bands. Old-growth Sitka spruce (*Picea sitchensis*) with an understory of Nootka reed grass (*Calamagrostis nutkaensis*) grows in a band along the coast, with scattered patches of dense spruce regeneration. I called this first band 'spruce habitat'. Western hemlock (*Tsuga heterophylla*) grow further inland with salal (*Gaultheria shallon*) or moss as the predominant understory. This habitat type forms the second band. Further inland, western hemlock is gradually replaced by western redcedar (*Thuja plicata*) which forms the third habitat type. Salal or moss occurs beneath the redcedars depending on the local soil moisture. The fourth major habitat type consists of the extensive bogs that cover the center of island and contain common juniper (*Juniperis communis*) and shore pine (*Pinus contorta* v. *contorta*). For some analyses, I grouped the hemlock, redcedar and open bog habitats and refer to them as 'interior habitats'. I also refer to the spruce habitat as 'coastal habitat.'

My study focused on 3 regions on Langara Island: the Ancient Murrelet colony, the South End, and the area surrounding Hazardous Cove. The Ancient Murrelet colony occupies the northeast corner of the island and extends 1900 m westward from

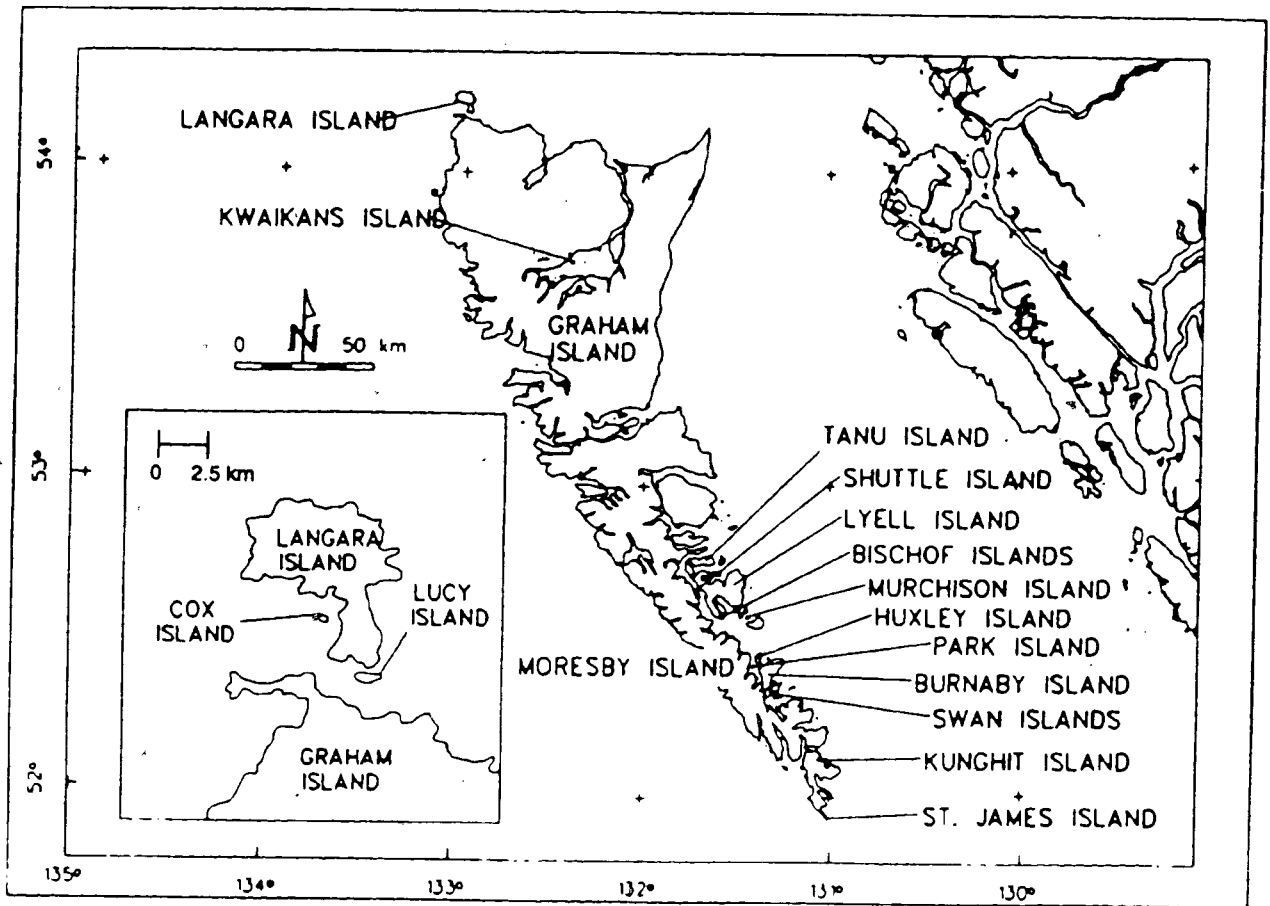


Figure 1. Islands with introduced rats (*Rattus* spp.) in the Queen Charlotte Islands (Haida Gwaii) of British Columbia, showing study site, Kiisgwaii (inset) (from Bertram and Nagorsen 1995).

McPherson Point, with a smaller section of 50 burrows on Explorer Bay (Harfenist 1994). Ancient Murrelets nest in burrows and begin breeding in April each year and most finish breeding by mid-June (Gaston 1994). The South End includes Henslung Cove and Dadens Point. This area receives the heaviest human traffic and contains up to 7 fishing lodges. Two lodges have luxury accommodations for guests on the island, and the remainder house their guests on barges or boats moored in the cove. The fishing season begins in May and continues until late September. The third region, Hazardous Cove, on the southwest side of Langara Island, contains several dense thickets of salal. During low tides, an extensive littoral zone becomes exposed that could serve as a rich source of food for Norway rats.

Lucy Island lies in Parry Passage, between Langara Island from Graham Island, and would be the 'stepping stone' for a recolonization of rats from Graham Island. It is flat and is covered by a predominantly Sitka spruce forest with some western hemlock and western redcedar. A dense understory of salal covers most of the island, and Nootka reed grass grows in tufts along the north, east and west coasts. Cox Island rises steeply out of the ocean and has Sitka spruce growing at its base and on its top.

CHAPTER 1

DIET OF NORWAY RATS ON LANGARA ISLAND

Introduction

The food habits of Norway rats on Langara Island are relevant to an eradication campaign. First, poison baits must compete with other food sources. Knowing what rats eat in the absence of bait can help to time the baiting campaign effectively. Second, in the absence of predators of rats on Langara Island, availability of food may limit numbers and distribution of rats. Thus, information on the diet of rats can aid in weighting a baiting system so that areas with abundant food sources receive more bait than areas where food is less abundant. Third, the diet of rats can provide evidence of movement and foraging ranges of rats, e.g., marine foods found in stomachs of inland rats. Fourth, diet information, obtained by examining stomach contents and stable isotope concentrations in the livers of rats, can assuage sceptics by providing direct evidence of rat predation on the island's bird populations.

Stable isotope studies enhance descriptions of stomach contents by providing time-integrated data based on the assimilated and not just recently-ingested foods. In particular, they can answer two questions. First, to what ~~extent~~ do inland rats feed in the coastal habitats? Second, does the proportion of heavy isotopes increase with trophic level in rats as it does in seabirds (Hobson *et al.* 1994)?

Isotopic models

Carbon and nitrogen exist in nature as two stable isotopes. The light isotopes, ^{12}C and ^{14}N , are more common than the heavy isotopes, ^{13}C and ^{15}N . The isotopic composition of any tissue can be expressed as a ratio of heavy:light isotope relative to a standard, as expressed in δ notation of parts per thousand (‰):

$$\delta X \approx [(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 1,000$$

where, X is ^{13}C or ^{15}N , and R is the corresponding ratio $^{13}\text{C}/^{12}\text{C}$ or $^{15}\text{N}/^{14}\text{N}$ of the sample or standard. Thus, tissues can have positive or negative δX values, and higher values denote higher amounts of the heavy isotope. Standard reference materials are limestone from the PeeDee formation of South Carolina for carbon and nitrogen gas in the atmosphere for nitrogen (Tieszen *et al.* 1983; Hobson *et al.* 1994).

The isotopic composition of animal tissue depends largely on diet and represents the assimilation of dietary protein. In particular, dietary information from the isotopic analysis of liver tissue integrates food assimilation over a week (Tieszen *et al.* 1983, Hobson and Clark 1992). An animal assimilates the stable isotope composition of its diet according to:

$$\delta_{\text{tissue}} = \delta_{\text{diet}} + \Delta t$$

where Δt , is the isotopic fractionation factor between dietary and consumer tissue (Peterson and Fry 1987). Generally, the tissues of animals become enriched in heavy carbon and particularly heavy nitrogen relative to their diet because of the preferential loss of light isotopes during excretion (Peterson and Fry 1987).

Stable-carbon isotope analyses have been used to examine the relative contributions of protein derived from marine and terrestrial ecosystems to the diets of diverse species (Hobson 1986, Peterson and Fry 1987, Peterson and Howarth 1987, Hobson and Sealy 1991). Marine and terrestrial prey typically have different $\delta^{13}\text{C}$ values because they differ in their source of carbon. Carbon enters marine ecosystems as dissolved carbonates, which have $\delta^{13}\text{C}$ values $\sim 0\text{‰}$, whereas carbon enters terrestrial ecosystems as atmospheric carbon dioxide, which has $\delta^{13}\text{C}$ values near -7‰ (Hobson 1991). Exclusive feeders on marine-based protein typically have tissues with $\delta^{13}\text{C}$ values $\sim 7\text{‰}$ greater than tissues of animals which feed only on terrestrial C-3 plant based proteins

(Chisholm *et al.* 1982). The tissues of animals which feed on both marine and terrestrial foods typically have $\delta^{13}\text{C}$ values intermediate between the two extremes.

Stable isotope analyses have been used to study trophic relationships between seabirds and their prey, and thus can be extended to include the predators of seabirds. The heavy nitrogen isotope increases step-wise with trophic level in the muscle and bone tissue of seabirds (Hobson *et al.* 1994). I sought to determine if rats feeding on seabirds have elevated $\delta^{15}\text{N}$ values relative to conspecifics feeding on prey from lower trophic levels.

Methods

Stomach contents

Norway rats were killed in Victor snap traps on Langara Island between April and July 1995. I removed their stomachs and preserved them at -10°C . Under a dissecting microscope, stomach contents were identified to food type using a reference collection gathered from the field and from the natural history collection at Simon Fraser University. I identified feathers following Day (1966). For each stomach, I recorded all food types, visually estimated the percent volume of each food type, and placed each type into 1 of 7 groups: fungi, fruits and seeds, plant shoots (including unidentified stem fragments), terrestrial invertebrates, marine invertebrates, fish, and birds. I compared the frequency of occurrence of different food groups between sexes of rats, as well as among habitats and regions, using Fisher's exact tests for contingency tables larger than 2×2 (Agresti 1996). The volumes of food groups were compared using Kruskal-Wallis tests. I used a Bonferroni-adjusted significance level ($\alpha=0.008$) to maintain an overall significance level of 0.05 for comparisons between sexes and among habitats and regions (Zar 1996).

Stable isotopes

The livers of Norway rats killed in snap traps were removed, preserved at -10°C , later freeze-dried, ground into powder, and loaded into tin cups, and combusted at $\sim 1800^{\circ}\text{C}$ in a Europa Robo-Prep Elemental Analyzer using a helium carrier gas interfaced with a Europa 2020 isotope ratio mass spectrometer (IRMS). This continuous flow IRMS technique provided both $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values with errors of $\pm 0.2\text{‰}$ and $\pm 0.3\text{‰}$ for carbon and nitrogen isotope, respectively. All samples were analyzed at the Prairie and Northern Wildlife Research Center and Department of Soil Science, University of Saskatchewan. I compared $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values between sexes and among regions and habitats using a multivariate ANOVA (PROC GLM in SAS), and Tukey's tests to contrast levels where factors were significant.

Results

Stomach contents

I identified 34 food types in 80 rat stomachs (Table 1). Some food types in advanced stages of digestion (7.5%) could not be identified. Five stomachs were empty, 22 stomachs contained only 1 food type, and some contained up to 6 food types (mean \pm SE = 2.31 ± 0.17 types per stomach, $n=80$). Food types that occurred in high frequencies and volumes included plant shoots, salal berries, Sitka spruce seeds, amphipods, parts of Ancient Murrelets and fungi (Fig. 2).

The percent occurrence and volume of each food group did not differ between males ($n=39$) and females ($n=41$) (Fisher's exact test and Kruskal-Wallis test, $P>0.05$). The percent occurrence of some groups varied with the habitat and region in which the rats were trapped (Figs. 3, 4). The percent occurrence and volume of birds in the diets of rats from the Ancient Murrelet colony were greater than in the diets of rats from the South

Table 1. Occurrence and volume of food types in stomachs of 80 Norway rats (*Rattus norvegicus*) trapped on Langara Island, British Columbia. Food types are listed in decreasing order of occurrence within groups.

Food Group	Food type	Number of stomachs containing food type	Number of stomachs by percent volume of contents		
			Low (<10%)	Medium (10-50%)	High (>50%)
Fruits and seeds	<i>Gaultheria shallon</i> (salal)	17	0	9	8
	<i>Picea sitchensis</i> (Sitka spruce)	9	2	4	3
	<i>Carex</i> spp. (sedge)	3	0	4	2
	<i>Vaccinium parvifolium</i> (red huckleberry)	3	3	0	0
	<i>Calamagrostis nutkaensis</i> (Nootka reedgrass)	2	2	0	0
	<i>Tsuga heterophylla</i> (western hemlock)	2	1	0	1
	<i>Juncus</i> spp. (rush)	1	1	0	0
Plant shoots	Unidentified	21	3	6	12
	<i>Tsuga heterophylla</i> (western hemlock)	7	5	2	0
	<i>Picea sitchensis</i> (Sitka spruce)	3	3	0	0
	<i>Juncus</i> spp. (rush)	3	2	0	1
	Moss	2	1	1	0
	<i>Vaccinium parvifolium</i> (red huckleberry)	1	0	1	0
	<i>Thuja plicata</i> (western redcedar)	1	1	0	0
	<i>Taxus brevifolia</i> (Pacific yew)	1	1	0	0
	<i>Alnus rubra</i> (red alder)	1	1	0	0
	Algae	1	1	0	0
Fungi	Unidentified	8	1	3	4
Terrestrial invertebrates	Orthoptera: Gryllidae (cricket)	6	2	4	0
	Arthropoda: Diplopoda (millipede)	2	0	2	0
	Coleoptera: Curculionidae (weevil)	1	1	0	0
	Coleoptera: Carabidae (carabid)	1	1	0	0
	<i>Haplotrema sportella</i> (land snail)	1	1	0	0
	Ephemeroptera (mayfly)	1	1	0	0
Marine invertebrates	Arthropoda: Amphipoda (amphipods)	15	4	3	8
	Arthropoda: Decapoda (crabs)	4	1	3	0
	Mollusca: Bivalvia (mussels)	3	0	2	1
	Mollusca: Gastropoda (snail)	1	0	1	0
Fish	Scales	6	3	2	1
	Flesh	3	0	0	3
	Roe	2	1	0	1
Birds	<i>Synthliboramphus antiquus</i> (Ancient Murrelet)	15	1	5	9
	Unidentified	2	2	0	0

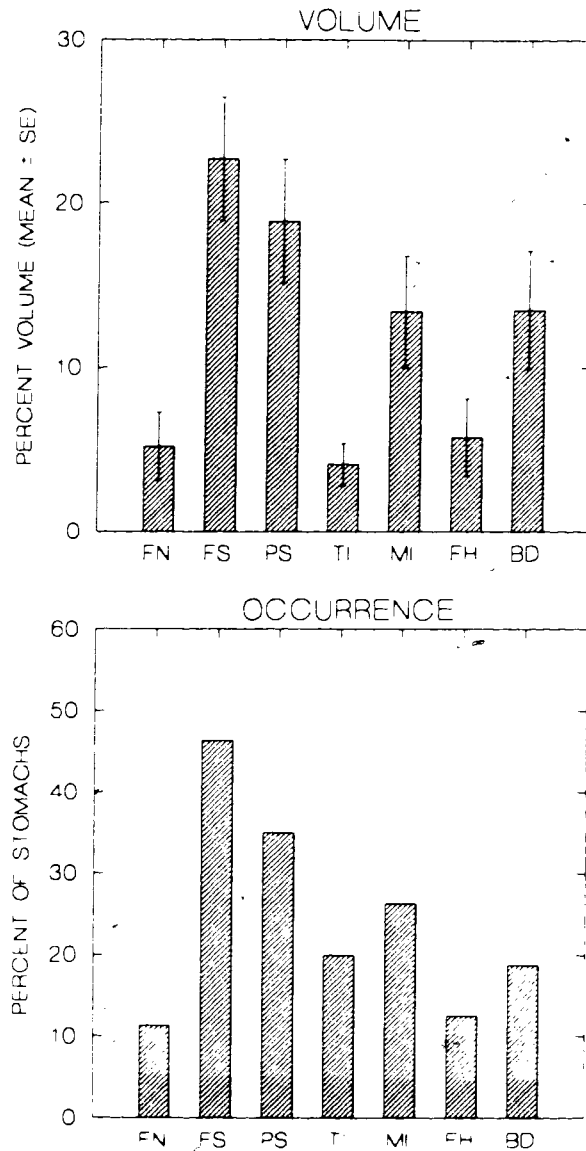


Figure 2. Percent occurrence and percent volume of food groups in stomachs of 80 Norway rats (*Rattus norvegicus*) trapped between April and July 1995 on Langara Island, British Columbia. Food groups are: FN, fungi; FS, fruits and seeds; PS, plant shoots; TI, terrestrial invertebrates; MI, marine invertebrates; FH, fish; BD, birds.

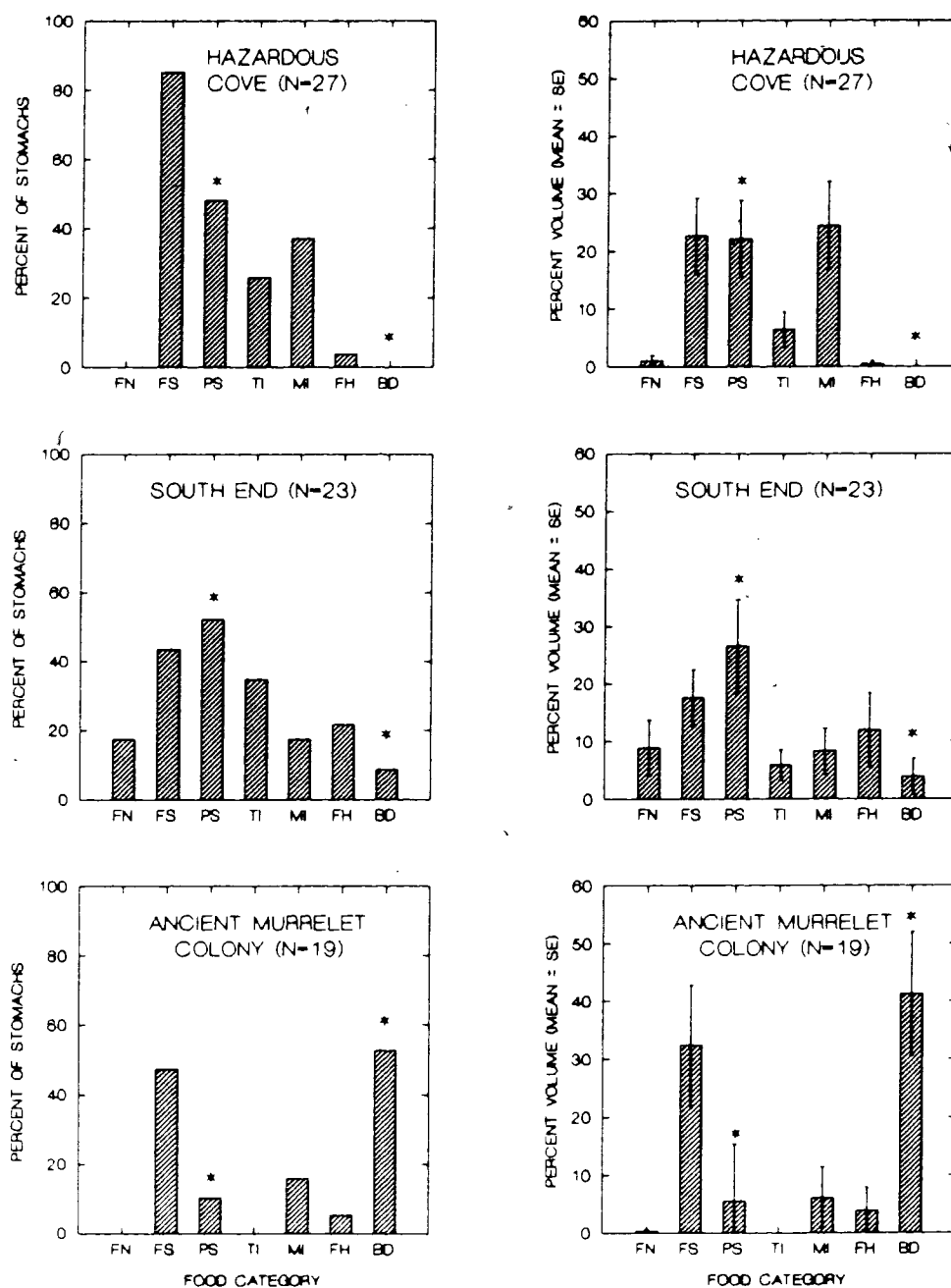


Figure 3. Percent occurrence and percent volume of food groups in stomachs of Norway rats (*Rattus norvegicus*) trapped between April and July 1995 in 3 regions on Langara Island, British Columbia. Food groups: FN, fungi; FS, fruits and seeds; PS, plant shoots; TI, terrestrial invertebrates; MI, marine invertebrates; FH, fish; BD, birds. Percents with asterisks are significantly different in occurrence (Fisher's exact test, Bonferroni adjusted significance level, $P < 0.008$) or volume (Kruskal-Wallis test, Bonferroni adjusted significance level, $P < 0.008$) among regions.

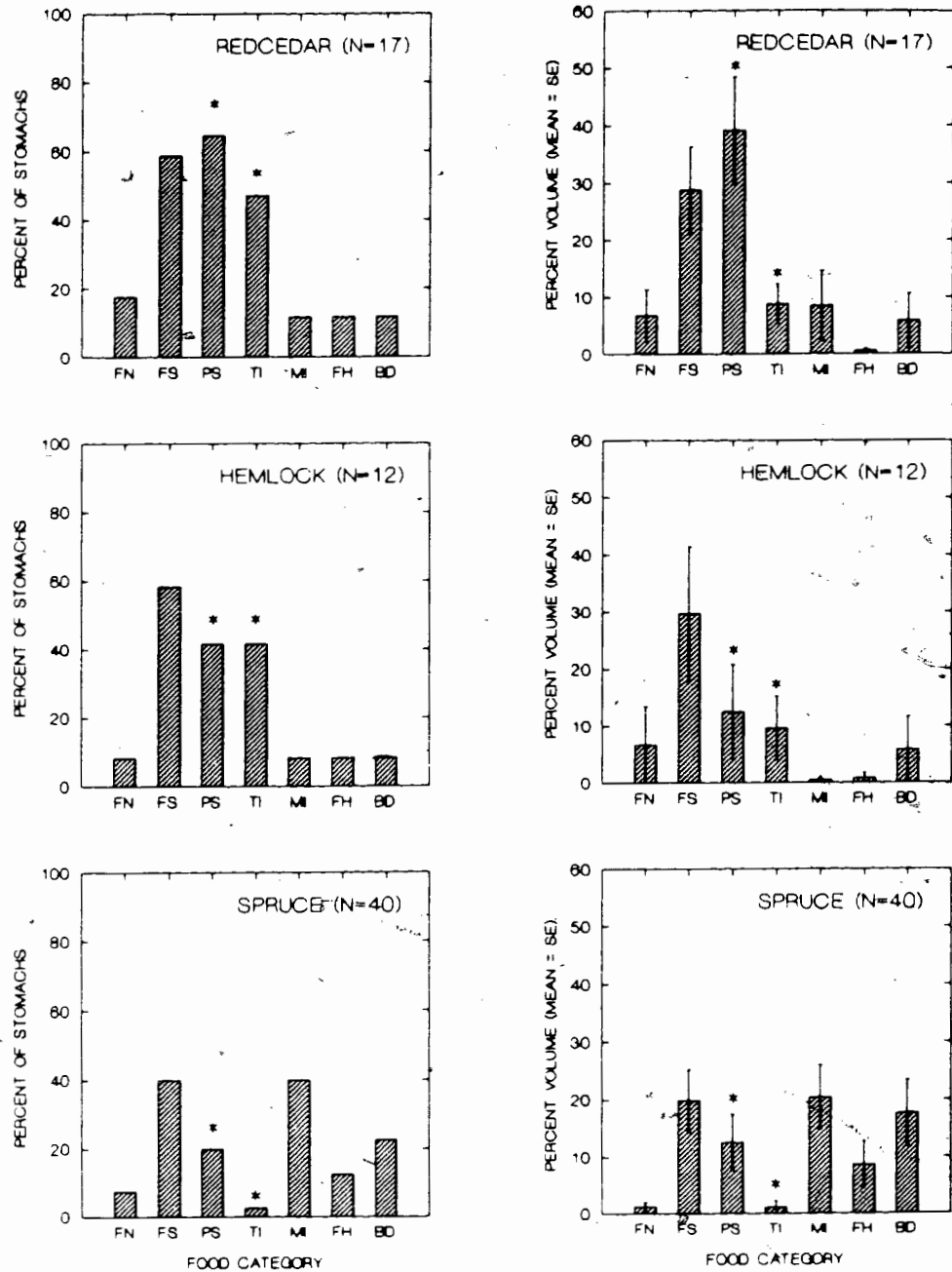


Figure 4. Percent occurrence and percent volume of food groups in stomachs of Norway rats (*Rattus norvegicus*) trapped between April and July 1995 in 3 habitats on Langara Island, British Columbia. Spruce habitat lies near the coast of the island. Hemlock and redcedar habitats are in the interior of the island. Food groups: FN, fungi; FS, fruits and seeds; PS, plant shoots; TI, terrestrial invertebrates; MI, marine invertebrates; FH, fish; BD, birds. Percents with asterisks are significantly different in occurrence (Fisher's exact test, Bonferroni adjusted significance level, $P < 0.008$) or volume (Kruskal-Wallis test, Bonferroni adjusted significance level, $P < 0.008$) among habitats.

End and Hazardous Cove (Fig. 3). The bird parts were mostly Ancient Murrelets, although feathers from an unidentified bird species were found in 2 stomachs from rats in the South End. Rats from the Ancient Murrelet colony also ate fewer plant shoots than did rats from other regions. The percent occurrences of plant shoots and terrestrial invertebrates were greater in the diets of rats from the hemlock and redcedar habitats than in the diet of rats from spruce habitat near the coast (Fig. 4). Three stomachs of rats trapped in interior habitats contained amphipods and 3 other stomachs of rats from interior habitats contained fish.

Stable isotope analysis

Concentrations of stable isotopes in livers differed significantly among regions and habitats (Fig. 5), but did not differ between sexes. Livers from rats caught in different regions had significantly different $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values (MANOVA: Wilke's Lambda $F_{4,90} = 15.34$, $P < 0.01$). The mean $\delta^{13}\text{C}$ value for rats from the South End differed significantly from those for rats from Hazardous Cove and the Ancient Murrelet colony. $\delta^{15}\text{N}$ values increased from the South End, to Hazardous Cove and to the Ancient Murrelet colony. Both $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values differed significantly among rats from different habitats (MANOVA: Wilke's Lambda $F_{4,90} = 15.66$, $P < 0.01$). Rats from hemlock and redcedar habitats had significantly lower mean $\delta^{13}\text{C}$ values than rats from spruce habitat (Tukey's test, $P < 0.05$). The rats from spruce habitat also had a significantly higher content of ^{15}N than rats in hemlock and redcedar habitats.

Discussion

My results provide strong, but indirect evidence in support of the hypothesis of Taylor (1993), Harfenist (1994) and Bertram (1995) that Norway rats are responsible for the declining numbers of Ancient Murrelets on Langara Island. In particular, tissues of

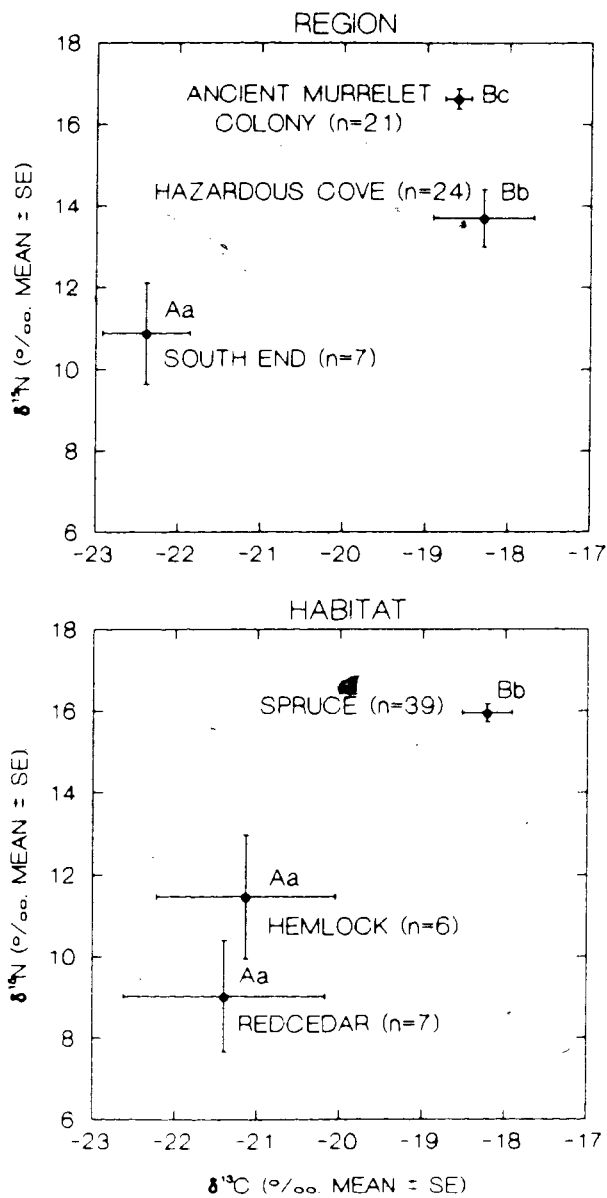


Figure 5. Stable carbon and nitrogen isotope concentrations in livers of Norway rats (*Rattus norvegicus*) from different regions and habitats on Langara Island, British Columbia. Sample size in brackets. Means for $\delta^{13}\text{C}$ with same capital letter, and for $\delta^{15}\text{N}$ with same lower case letter, are not significantly different.

Ancient Murrelets were found in 53% of stomachs from rats trapped in the Ancient Murrelet colony, and on average, constituted 41% of the contents of these stomachs. Because most of the rats from the seabird colony were trapped in July, after most of the Ancient Murrelets had finished breeding (Gaston 1994), these data may underestimate the importance of Ancient Murrelets in the diet of rats on Langara Island.

Most of the unidentified partially-digested plant shoots in the stomachs were probably salal. During spring and early summer, I often found salal with their growing tips removed, and the distribution of rats was positively associated with percent cover of salal (see Chapter 3). The frequent occurrence and high volume of plant material in the stomachs suggest that plants are staple foods of Norway rats on Langara Island, as they are on islands elsewhere (Wirtz 1972, Pye and Bonner 1980, Clark 1981, Moors 1985b, Taylor and Thomas 1993, Amarasekare 1994).

Norway rats appear to exploit the highest quality and most readily available food items depending on the region and habitat. For example, the incidence of plant shoots in the diets increases with distance from the ocean (Figs. 3, 4), which suggest that near the ocean other foods were available and readily eaten. In addition, terrestrial invertebrates, which are higher in protein and have a greater variety of essential amino acids than most plants (Needham 1964, Clark 1981, Moors 1985b), were consumed in greater frequencies and volumes in the interior habitats. Near the coast, amphipods and other marine invertebrates provide much of this protein. Several species of amphipods are nocturnal, feed in large masses on vegetation at or near the high-tide line on exposed beaches (Kozloff 1993), and thus are available when rats are most active.

The presence of amphipods in stomachs of 3 rats from inland habitats up to 500 m from the coast suggests that rats forage widely, and at least some rats reach the littoral zone occasionally. Two of these rats were males, which are known to move long distances on other islands (Taylor and Thomas 1993). The presence of fish in the stomach

of inland rats does not necessarily support the hypothesis of long-range movement, because Bald Eagles (*Haliaeetus leucocephalus*) and other scavengers often drop pieces of their prey inland, thus making them available to rats.

The isotopic and stomach contents are mutually supportive. The livers of coastal rats, which fed heavily on marine invertebrates and fish (Fig. 4) had $\delta^{13}\text{C}$ values that averaged -18.2‰ (Fig. 5), which implies a marine protein contribution in the diet of 68% based on a model analogous to Hobson and Sealy (1991). This estimate is in agreement with the high volume of marine foods (marine invertebrates, fish and birds) in the stomachs of rats trapped in spruce habitat. Conversely, the inland rats, which feed primarily on plants and terrestrial invertebrates (Fig. 4), had livers with $\delta^{13}\text{C}$ values that averaged $-21.3 \pm 0.8\text{‰}$ (all inland samples pooled, $n = 13$), which indicates little marine protein in their diets (Hobson and Sealy 1991). Rats from hemlock and redcedar habitat have 7.1% and 9.1% of marine foods by stomach volume, respectively (discounting the 2 incidences of bird which were not Ancient Murrelets). Thus, it appears that rats in the interior rarely feed in the littoral zone, perhaps because of exclusion by their coastal conspecifics.

The similar $\delta^{13}\text{C}$ levels in the livers of Norway rats from Hazardous Cove and the Ancient Murrelet colony suggest that rats from both regions obtain the same amount of protein from marine sources. However, Norway rats that prey on seabirds have $\delta^{15}\text{N}$ values averaging 16.6‰ , whereas the rats from Hazardous Cove have $\delta^{15}\text{N}$ values averaging 13.7‰ . This difference suggests the Hazardous Cove rats feed at a lower trophic level (Hobson *et al.* 1994). Furthermore, Ancient Murrelet eggs from Langara Island typically have $\delta^{15}\text{N}$ values averaging $13.3 \pm 0.05\text{‰}$ ($n = 4$, Dr. Keith Hobson, Canadian Wildlife Service, Prairie and Northern Wildlife Research Centre, pers. comm.), which indicates an isotopic fractionation value of $+3.3\text{‰}$ that is similar to estimates of 3 to 5‰ reported for other marine systems (Mizutani *et al.* 1991, Hobson *et al.* 1994). The

elevated $\delta^{15}\text{N}$ values for the rats eating Ancient Murrelets relative to rats from Hazardous Cove indicate that stable isotope analyses can be used to determine the occurrence of seabirds in the diet of rats. This information would be particularly useful to confirm the safety of apparently rat-free refugia, e.g., Cox Island, where seabirds breed at the top of a tall stone tower.

The low $\delta^{13}\text{C}$ values of rats in the South End indicate that they depend less on the marine food resources than do rats elsewhere on the island. The beaches near the South End of Langara Island are sandy, and may not harbour as much marine food as the flat rock beaches of Hazardous Cove and the Ancient Murrelet colony. In addition, the fishing lodges at the South End may provide garbage that supplements the rats' diet.

I found no statistically significant differences in volumes of food groups between the diets of male and female rats, and among some habitats and regions. The power of the Fisher's exact tests and Kruskal-Wallis tests however was very low. It ranged from 0.01 to 0.51 where differences between groups were non-significant, below the recommended power of 0.80. The minimum detectable difference between groups was ~25% volume or occurrence, and thus I could only detect gross differences in diet.

The dietary plasticity of the Norway rats underscores the importance of using a very attractive bait over the entire island. If rats were killed only along the coast, recruits from the interior will move to the vacant sites (Innes and Skipworth 1983; Taylor 1986). On large islands, even long term coastal baiting will not eradicate rats because the inland habitat will sustain rat populations at low densities. The importance of seeds and shoots in the diet of the Norway rats implies that a poison campaign during winter, when these foods are least available, would maximize bait uptake. However, stormy weather during winter creates a high hazard to humans, and the large manpower needs of a project this size preclude a winter campaign.

CHAPTER 2

MONITORING NORWAY RATS ON LANGARA ISLAND

Introduction

Effective monitoring provides baseline information on the status of pest populations for pest management operations. Monitoring for rats on oceanic islands has included livetrapping, snaptrapping, and the use of indicator baits such as fresh apples and chew sticks (Pye and Bonner 1980, Clark 1981, Moors 1985a). My objective was to compare 3 techniques for monitoring populations of Norway rats on Kiisgwaii: (1) livetrapping using a combination of trap-types; (2) snaptrapping; and (3) using indicator baits. The results were intended for use in selecting an optimal technique for evaluating the rat eradication program on Langara Island.

Methods

Snaptrapping

Two snaptrapping sites were chosen in the seabird colony (No Name Point and McPherson Point), 2 on the South End (Henslung Cove and Dadens Bay), and 2 near Hazardous Cove (Hazardous Cove East and Hazardous Cove West) (Fig. 6). At each site, 3 trap lines were established, each 400 m long and consisting of 16 traps spaced 25 m apart. The trap lines ran parallel to the shoreline, and each line sampled 1 of 3 habitat types (Sitka spruce, western hemlock, or western redcedar). The trap lines were 25 to 200 m apart at each site depending on the width of the habitat. Whenever possible, traps were placed under cover of vegetation.

Each site was sampled in May and June before the start of the poisoning campaign using Victor snap traps baited with a mixture of rolled oats and peanut butter. A third

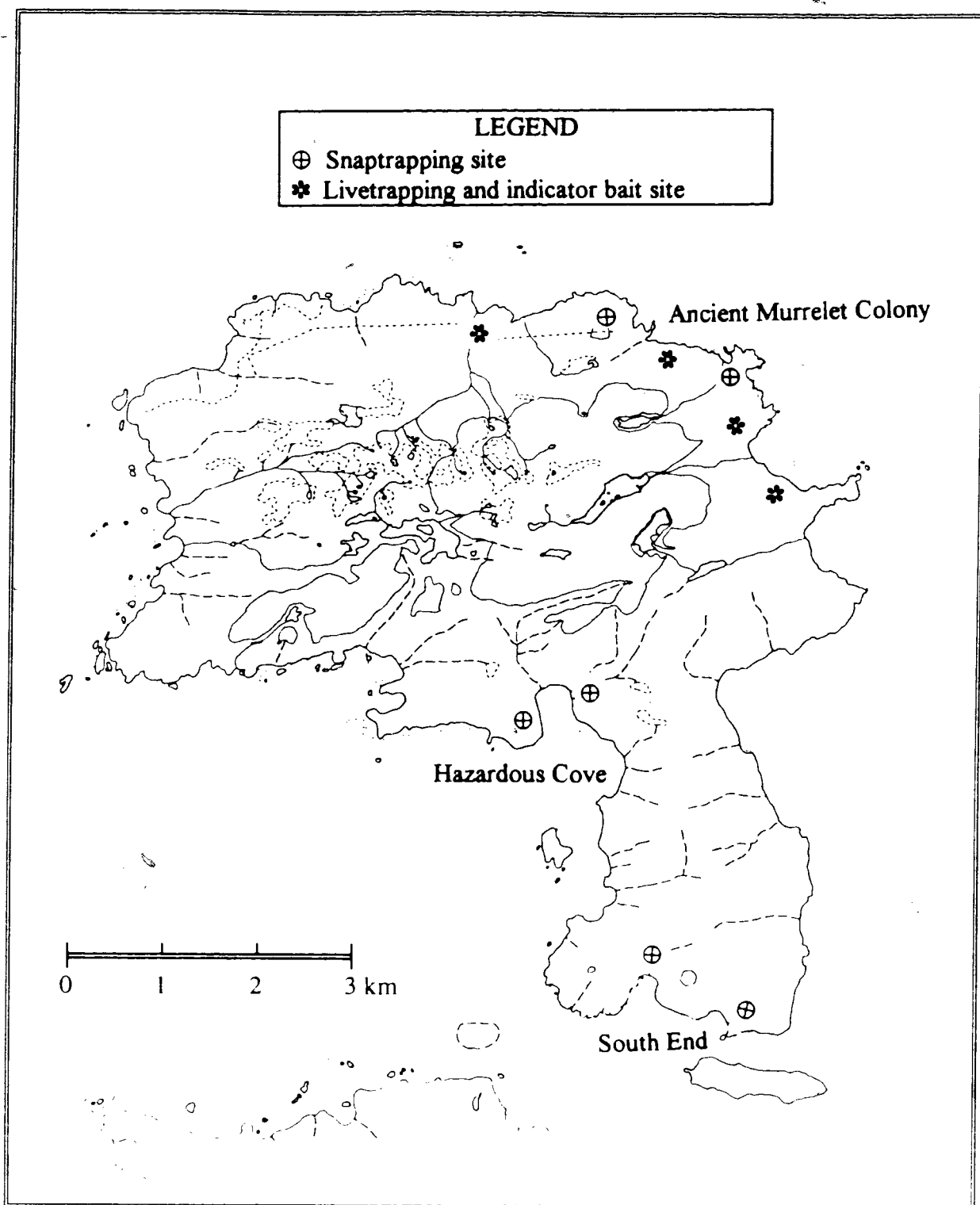


Figure 6. Location of monitoring sites on Langara Island, British Columbia.

trapping session was conducted in early July in the seabird colony prior to the eradication program. Each sampling period consisted of 3 nights during which traps were checked every 24 h. Rats killed in the traps were sexed, weighed, measured, and their reproductive state noted. Catches were expressed in number of animals (C) caught per 100 trap nights (TN) to allow comparisons between areas with different trapping efforts. I corrected trapping effort for the number of traps sprung during the night, and thus rendered unavailable (Nelson and Clark 1973).

Livetrapping

Four grids of 49 traps (7×7) were established within the Ancient Murrelet colony, using 42 large Sherman traps and 7 Tomahawk traps for each grid. The traps were spaced 25 m apart and arranged so that each line running parallel to the shore had 1 randomly-placed Tomahawk trap. The traps were left unbaited and locked open for 2 weeks to allow rats to acclimate to their presence. Thereafter, the traps were baited with peanut butter and rolled oats. Coarse brown cotton was placed in each trap for bedding. Traps were set for 4 consecutive nights in late May, and all Norway rats caught were sexed, weighed, ear-tagged and released at their point of capture. Health (i.e., signs of poisoning, scars) and reproductive status were also noted. Other captured animals were released at their point of capture or buried away from the grid if they died in the traps. All animals were handled using leather gloves and a canvas holding bag.

Apples and indicator pellets

Apples have been used as indicators of rat activity in New Zealand (Taylor and Thomas 1989, Taylor and Thomas 1993). Fresh apples are a preferred food of rats and their texture allows for easy identification of tooth marks (Taylor and Thomas 1989). Ten monitoring stations were marked with flagging tape in each of the 4 livetrapping grids in the Ancient Murrelet colony. At each station, halves of apples were staked near cover 4-5

cm above the ground, and left for 2 days. Each station was checked in the morning, and any apple halves removed during the night or with evidence of rat feeding, particularly incisor marks, were replaced.

In addition to the 10 stations with apples, 10 monitoring stations with dog food pellets were set up at each livetrapping grid. Each consisted of a 7.5 cm diameter plastic petri dish placed beneath cover containing 5 pellets of dry dog food. The pellets were left overnight and checked the following 2 days. At each station, the number of pellets taken during 24 h was noted, as was the condition of the remaining pellets. Any pellets removed or partially consumed during the night were replaced.

Results

Most of the animals caught in snap traps were Norway rats and dusky shrews (*Sorex monticolus*). In addition, 1 Northwestern Crow (*Corvus caurinus*) and 2 Fox Sparrows (*Passarella iliaca*) were trapped. Snaptrapping in the Ancient Murrelet colony during May and June, when the birds were breeding, resulted in extremely low capture rates of rats (0.0 to 0.7 C/100 TN), while capture rates at other sites on the island ranged between 2.2 to 17.1 C/100 TN (Table 2). In early July, after most of the murrelets finished breeding, capture rates of rats in the 2 seabird colony sites increased to 9.9 and 14.0 C/100 TN.

Capture rates of Norway rats on the livetrapping grids were extremely low (0.0 - 0.5 C/100 TN). During 4 nights of trapping, 2 Norway rats were caught, 1 male (232 g) and 1 female (240 g), in 2 different grids (Table 3). Dusky shrews were trapped at 3 of the 4 grids, in numbers ranging from 9 to 22 shrews per grid over the 4 nights. In addition, apples showed signs of rat feeding on 3 of the 4 grids, even where rats were not trapped (Table 3). Occasionally, entire apple halves disappeared, or were found pecked by birds, likely crows or ravens.

Table 2. Capture rates of Norway rats (*Rattus norvegicus*) and dusky shrews (*Sorex monticolus*) in snap traps in 1995 at 6 sites on Langara Island, British Columbia. Catches were corrected for unavailable traps (Nelson and Clark 1973).

Region	Site	Catch per 100 trap nights					
		<i>Rattus norvegicus</i>			<i>Sorex monticolus</i>		
		May	June	July	May	June	July
Ancient Murrelet Colony	McPherson Point	0.0	0.7	9.9	0.0	7.4	11.6
	No Name Point	0.0	0.0	14.0	0.0	0.0	0.0
South End	Henslung Cove	5.9	3.6	-	2.9	7.3	-
	Dadens Point	8.1	2.2	-	0.0	6.6	-
Hazardous Cove	Hazardous Cove West	17.1	12.0	-	0.0	5.8	-
	Hazardous Cove East	5.5	10.5	-	0.0	7.9	-

Table 3. Number of Norway rats (*Rattus norvegicus*) and dusky shrews (*Sorex monticolus*) caught in live traps and feeding at indicator bait stations in the Ancient Murrelet colony on Langara Island, British Columbia, May 1995.

Grid	Number caught per 196 trap nights		Feeding sign on apples per 20 apple nights			Pellets of dog food removed per 20 station nights
	<i>Rattus norvegicus</i>	<i>Sorex monticolus</i>	Rat incisor marks	Shrew incisor marks	Entire apple removed	
1	0	0	1	2	0	4
2	1	9	0	2	0	10
3	0	6	5	2	2	9
4	1	22	3	5	0	8

Discussion

Differences in capture rates of Norway rats between trap lines in the Ancient Murrelet colony and those in regions away from the colony suggest that the presence of seabirds undermines the attractiveness of peanut butter and oats as bait. Feeding sign on apples by rats confirmed their presence in the seabird colony during May when the murrelets were nesting. Furthermore, capture rates of rats in the seabird colony rose sharply in July, coinciding with the departure of most of the murrelets (Gaston 1994). During the murrelet breeding period, I found cached chicks and adult murrelets, evidence of intense predation by rats. Thus, the rats likely avoided the traps and focused instead on murrelets, a more attractive prey than peanut butter. Alternatively, rats in the seabird colony might exist at lower population levels than in other regions of the island following winter and, on a murrelet protein diet, rapidly increase to densities similar to other regions on the island.

Harfenist (1994) and Bertram (1995) also reported low capture rates of rats in the Ancient Murrelet colony during the breeding season, emphasizing the desirability of conducting eradication campaigns when the birds are not breeding. The low capture rates during the murrelet breeding season indicate that monitoring rat populations by trapping while the birds are breeding will be difficult. Furthermore, trapping for telemetry work and other research must also be conducted before or after the breeding season of the seabirds.

The success of snaptrapping outside the seabird colony demonstrates the value of this technique to monitor rat populations in the absence of breeding seabirds. Snaptrapping removes animals from the population, and thus cannot readily provide population estimates. Data reported in terms of catch per unit effort can be useful however in monitoring relative changes in population size.

Livetrapping also yielded few rats, and suffered from the same ineffectiveness as snap traps during the breeding season of the Ancient Murrelets. Some of the failure to capture rats in live traps may have resulted from the inadequacy of the Sherman traps, because both of the captured rats were in Tomahawk traps, similar to the wire-cage traps used in New Zealand (Moors 1985a). Tomahawk traps also caught large numbers of rats after the murrelet breeding season (Chapter 4). Thus, the low capture rates in the live traps likely resulted from both the presence of seabird prey and type of traps used.

The ability of the apples to attract rats during the murrelet breeding season demonstrates the utility of this method to monitor presence of rats within a seabird colony and to determine efficacy of eradication, as found for rats at low densities in New Zealand (Taylor and Thomas 1989, Taylor and Thomas 1993). In contrast, dog food pellets provided only a general index of small mammal activity because it was impossible to distinguish shrew activity from that of rats.

CHAPTER 3

DISTRIBUTION AND HABITAT USE BY NORWAY RATS

Introduction

All previous research about rats on Kiisgwaii focused on determining the presence of rats in the Ancient Murrelet colony during breeding season (Harfenist 1994, Bertram 1995). Trapping in 1993 and 1994 confirmed the presence of Norway rats on Lucy Island (Taylor 1993, Bertram 1995), but not Cox Island. To be successful, eradication must include all 3 islands. Rats can swim the 200 m of ocean which separates these islands at low tide (Spennemann and Rapp 1989, Taylor 1993). Thus, trapping was needed to determine the presence and species of rats on Cox Island.

Information on the inland distribution of rats, which would aid the eradication attempt, particularly in setting habitat-specific baiting levels, was not available. I sought to provide this information in two ways: (1) by snaptrapping at the same intensity in different habitats, and (2) by examining the plant community at active and inactive bait stations. The first approach provides information on relative density of rats. The second approach involves differentiating 'active' bait stations (those from which poison was removed) and the 'inactive' bait stations (those from which poison was never removed) during the eradication campaign. Removal of baits at the bait station is a reliable index of rat activity. Rats are the only small mammals on the island which can remove entire bait blocks. Shrews only nibble on the baits, leaving small marks very different from the large incisor marks left by rats. This information was collected after the eradication campaign began and thus may be useful in planning future eradications in similar ecosystems.

Methods

Snaptrapping on Cox Island

To determine the presence and species of rats on Cox Island, 7 snap traps were placed on the beach and in the spruce forest at the base of the rock cliffs at locations near sign of rat activity (tracks and feces). These traps were baited with peanut butter and rolled oats, set, and checked daily for 3 trap nights.

Snaptrapping in different habitats on Langara Island

The snap traps placed along transects to sample in Sitka spruce, hemlock, and redcedar habitats (Chapter 2) were used to assess rat populations in different habitats. In addition, a 300-m trap line with 12 Victor snap traps was established to sample upland bogs. The traps were spaced 25 m apart, baited with peanut butter and oats, and checked every 24 h for 3 trap nights concurrently with the trapping sessions in the seabird colony during June and July, 1995. Capture rates of Norway rats and dusky shrews were compared using a general linear model (PROC GLM in SAS) constructed to express capture rate as a function of habitat, region and trapping session. Student-Newman-Keuls tests were used to contrast levels where factors in the model were significant. The data were transformed by $X' = \sqrt{X + 0.5}$ to correct for the large number of zero observations (Zar 1996). The May and June trapping sessions in the seabird colony were omitted from analysis because of extremely low capture rates.

To determine if Norway rats (adults only) differed among habitats, morphological measurements (weight, head-body length (HBL), and total length) were compared using a general linear model (PROC GLM in SAS) constructed to express each of these variables as a function of sex, habitat and region. I also calculated a body condition index (BCI) *sensu* Davis and Hall (1951) using the formula:

$$BCI = \frac{W}{HBL^3} \times 10^5$$

where, W is weight (g) and HBL is the head-body length (mm). This index can reveal differences in habitat quality, and was analyzed as described for the morphological measurements, although I included both adults and juveniles.

Habitat characteristics at bait stations

Thirty active and 30 inactive bait stations in the northeast corner of Langara Island were randomly chosen. Eight habitat characteristics were used to describe the surroundings at each of these bait stations: *slope*, the pitch of ground at the bait station, defined in degrees down from horizontal, and assigned to 1 of 3 categories (0-10°, 10-20°, >21°); *aspect*, the cardinal direction of the ground at the bait station, defined as flat, south-facing or north-facing; *coarse woody debris (CWD)*, defined as downed woody material > 20 cm in diameter and > 3 m in length, each bait station received a rank of low (0-1 pieces), medium (2-5 pieces), or high (> 5 pieces) for the amount of CWD within a 5 m radius of the bait station; *distance to nearest CWD*, distance from the bait station to the nearest piece of CWD, each bait station was placed into 1 of 4 categories (0-1 m, 2-5 m, 6-10 m and > 10 m); *percent cover of the herb layer*, percent area covered by vegetation below a height of 0.5 m in a 2-m circular plot around the bait station, each station was placed into 1 of 4 categories (0-25%, 26-50%, 51-75%, and 76-100%); *percent cover of the shrub layer*, percent area covered by vegetation below 2m and above 0.5 m in a 2-m circular plot around the bait station, each station was placed into 1 of 4 categories (0-25%, 26-50%, 51-75%, and 76-100%); *percent cover of the tree layer*, the percent area covered by vegetation above 2 m in a 2-m circular plot around the bait station, each station was placed into 1 of 4 categories (0-25%, 26-50%, 51-75%, and 76-100%); and *dominant species*, the plant species occupying the greatest area within each vegetation layer (herb, shrub, tree). I compared distributions of habitat characteristics and percent

cover between active and inactive bait stations using Fisher's exact tests (Agresti 1996). A Bonferroni-adjusted significance level was used for comparing habitat characteristics ($\alpha=0.01$) and percent cover ($\alpha=0.02$) to maintain an overall significance level of 0.05 for the 2 sets of comparisons. I used Fisher's exact test to compare the distributions of dominant species at active and inactive bait stations. Contingency tables with significant overall differences in distributions of dominant plant species were partitioned to examine differences among individual plant species. I used a Bonferroni-adjusted significance level ($\alpha=0.007$) to maintain an overall significance level of 0.05 for these partitioned comparisons.

Results

Snaptrapping on Cox Island

Three adult Norway rats, 2 females and 1 male, were caught in 21 trap nights (14.3 C/100 TN).

Snaptrapping in different habitats on Langara Island

Capture rates of rats differed significantly among habitats (Fig. 7). Capture rates in spruce habitat averaged 16.9 C/100 TN, approximately triple the capture rates in the hemlock, 4.7 C/100 TN, and redcedar, 4.9 C/100 TN, habitats (Student-Newman-Keuls test, $P < 0.05$). Rats were not caught in the upland bogs. Capture rates of dusky shrews ranged between 2.4 and 5.2 C/100 TN, but did not differ significantly among habitats, except for the upland bogs where shrews were not caught (Fig. 7).

None of the morphological measurements or BCI varied significantly with habitat or region, although females had a significantly higher BCI than did males across all habitats and regions (Table 4).

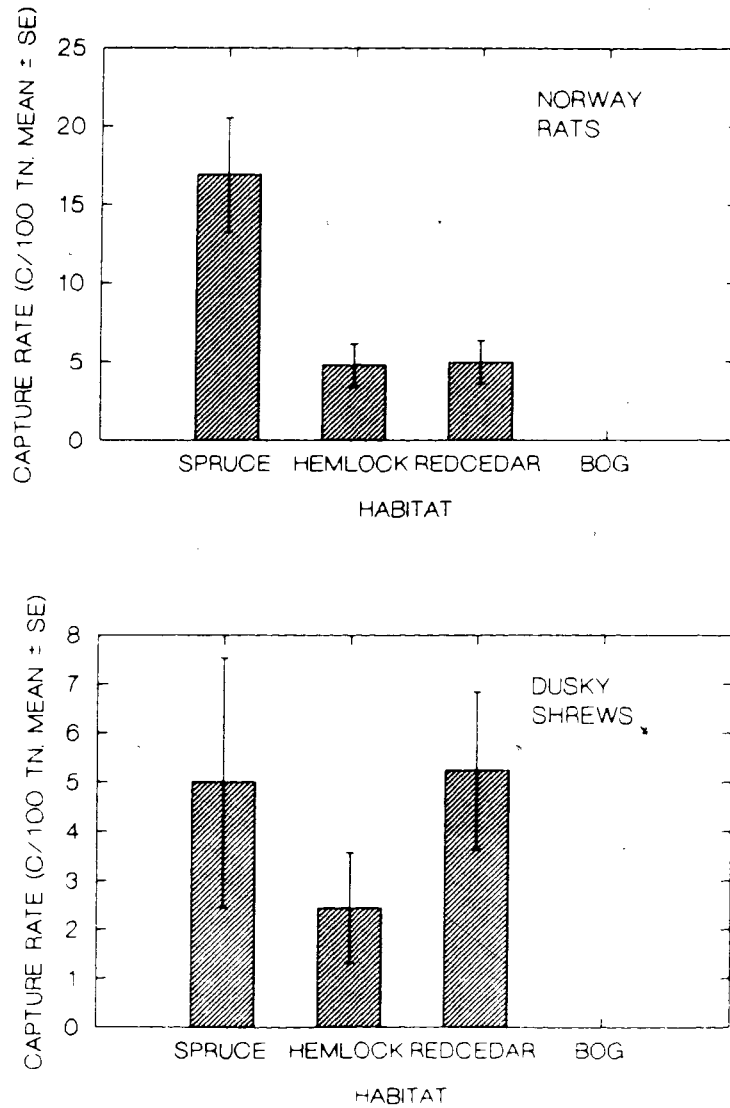


Figure 7. Capture rates of Norway rats (*Rattus norvegicus*) and dusky shrews (*Sorex monticolus*) in 4 habitat types during May-June 1995 on Langara Island, British Columbia. Capture rates are corrected for traps made unavailable during the night (Nelson and Clark 1973). Capture rates are significantly different among occupied habitats for rats ($F = 9.36$, $df = 2$, $P < 0.01$), but not shrews.

Table 4. Body measurements of Norway rats (*Rattus norvegicus*) trapped on Langara Island, British Columbia. Sizes are from reproductively mature rats. Body condition indices (all age classes) are significantly different between sexes ($F=11.35$, $df=1$, $P<0.01$).

Characteristic	Males			Females		
	N	Mean	Range	N	Mean	Range
Weight (g)	43	262	154-355	48	278	169-480
Head-body length (mm)	43	216	179-241	48	211	168-253
Total length (mm)	43	387	299-443	48	385	315-458
Body condition index (BCI)	47	2.65	1.90-4.00	50	2.91	2.33-4.11

Habitat characteristics

Slope, aspect, CWD, distance to nearest CWD, and percent cover of tree canopy did not differ significantly between active and inactive bait stations (Fig. 8). However, active and inactive bait stations differed in percent cover of both the herb and shrub layers (Fig. 9). Proportionally more active bait stations occurred in areas of sparse herb cover than in areas of high herb cover. Conversely, proportionally more active bait stations occurred in areas with high than low shrub cover.

The distributions of dominant plant species differed significantly at the shrub layer, but did not differ significantly at the herb or tree canopy vegetation layers (Table 5). Active bait stations were associated with the presence of salal in the shrub layer. Similarly, active bait stations were associated with red huckleberry, but not at the Bonferroni-adjusted significance level. Western hemlock in the shrub layer was associated with inactive bait stations.

Discussion

The presence of Norway rats on Cox Island confirms that rats have colonized all the islands in Kiisgwaii, all of which are within swimming distance of each other for rats at water temperatures from temperate latitudes (Spennemann and Rapp 1989, Taylor 1993). The capture rate of rats on Cox Island was similar to that in the coastal habitat on Langara Island, suggesting that rat populations densities are similar on the two islands.

The higher BCI for females than males on Langara Island (Table 4) differs from observations on the Noises Islands (Moors 1985b) and St. Clements Island (Lattanzio and Chapman 1980), where BCI did not differ between sexes. When the pregnant females were removed from the analysis, females still had a higher BCI than males ($F = 8.60$, $df = 2$, $P < 0.01$). However, only obviously pregnant females were noted during data

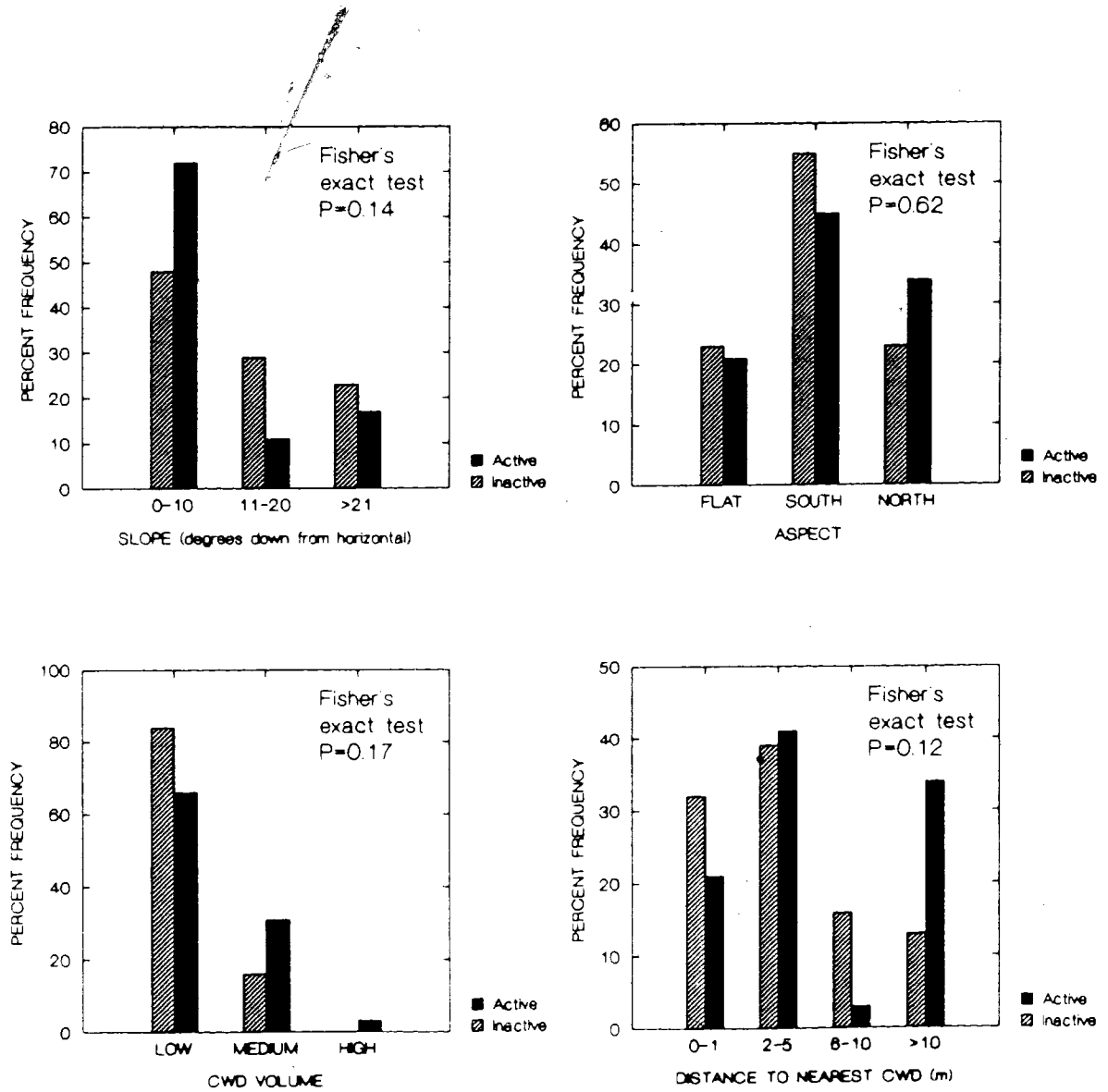


Figure 8. Habitat characteristics of 30 active and 30 inactive bait stations on Langara Island, British Columbia. These habitat characteristics did not differ significantly between active and inactive bait stations. See text for definitions.

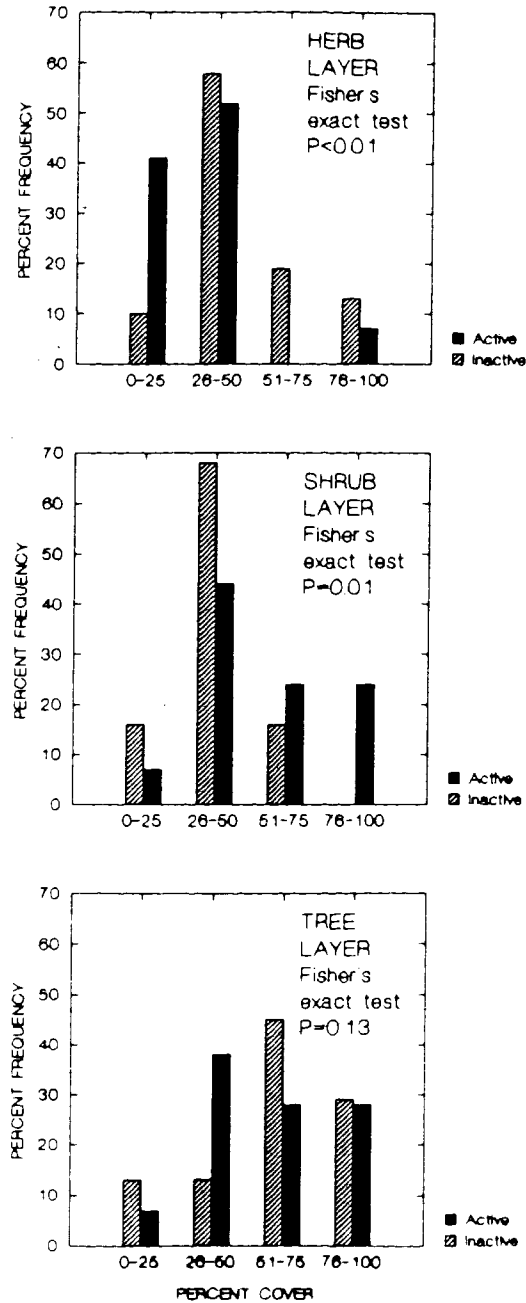


Figure 9. Percent cover of vegetation strata at 30 active and 30 inactive bait stations on Langara Island, British Columbia. See text for definitions.

Table 5. Frequencies of dominant plant species at active and inactive bait stations on Langara Island, British Columbia. Species are ordered from most frequent to least frequent within vegetation layers. "Active" means bait was taken from stations and indicates presence of Norway rats (*Rattus norvegicus*). "Inactive" means bait was not taken from stations and indicates rats were likely absent or at low densities. Analysis for individual plant species was performed only where test was significant for vegetation layer.

Dominant plant species	Percent of inactive stations with dominant species (N=30)	Percent of active stations with dominant species (N=30)	Fisher's exact test, P
<u>Tree layer</u>			
<i>Thuja plicata</i> (western redcedar)	35.5	62.1	0.11
<i>Alnus rubra</i> (red alder)	32.3	10.3	
<i>Tsuga heterophylla</i> (western hemlock)	12.9	20.7	
<i>Thuja plicata</i> / <i>Tsuga heterophylla</i>	9.7	6.9	
No canopy	6.5	0.0	
<i>Pinus contorta</i> v. <i>contorta</i> (shore pine)	3.2	0.0	
<u>Shrub layer</u>			
<i>Gaultheria shallon</i> (salal)	22.6	62.1	<0.01
<i>Tsuga heterophylla</i> (western hemlock)	32.3	3.5	<0.01
<i>Vaccinium parvifolium</i> (red huckleberry)	3.2	20.7	0.05
No shrubs	16.1	6.9	0.43
<i>Alnus rubra</i> (red alder)	9.7	6.9	1.00
<i>Thuja plicata</i> (western redcedar)	9.7	0.0	0.24
<i>Pinus contorta</i> v. <i>contorta</i> (shore pine)	6.5	0.0	0.49
<u>Herb layer</u>			
<i>Gaultheria shallon</i> (salal)	54.8	34.5	0.06
No herbs	9.7	37.9	
<i>Pteridium aquilinum</i> (bracken fern)	9.7	17.2	
<i>Tsuga heterophylla</i> (western hemlock)	12.9	3.5	
<i>Trifolium repens</i> (white clover)	6.5	6.9	
<i>Juniperis communis</i> (common juniper)	3.2	0.0	
<i>Pinus contorta</i> v. <i>contorta</i> (shore pine)	3.2	0.0	

collection, and thus females in earlier stages of pregnancy likely biased this analysis. Furthermore, because male and female rats consume similar prey, and the number of empty stomachs did not differ between males and females, weight differences do not likely arise from different food habits (Chapter 1).

Trapping success of rats on oceanic islands typically varies between 5-20 C/100 TN (Moors 1990). Densities of rats on Langara, Cox and Lucy Islands ranged within the normal variability of Norway rats in wilderness environments. Differences in capture rates among habitats on Langara Island suggest that densities of Norway rats are higher near the coast than those further inland. These higher densities could result from higher reproductive rates and/or lower mortality rates. The inland rats consume primarily plant material and derive most of their protein requirements from terrestrial invertebrates (Chapter 1). The abundance of these food groups likely cycles seasonally, resulting in heavy mortality in the fall and winter when production of new shoots and fruits declines. The coastal environment has greater availability of protein-rich foods (e.g., amphipods, molluscs) than interior habitats. Clark (1981) hypothesized that available animal protein limits the densities of rats on the Galapagos Islands. Gestation period, resorption rate of embryos, birth weight and neonatal growth rate of Norway rats depend on the availability of protein (Woodside *et al.* 1981). Thus, rats living in coastal environments likely have higher reproductive rates, and thus higher densities, than rats in interior habitats.

The different densities of rats among habitats contrasts with densities of dusky shrews, which showed no differences in capture rates among habitats. Shrews eat primarily terrestrial invertebrates and seeds (Nagorsen 1996), which are likely broadly distributed among habitat types, and thus do not differentially limit shrew abundance.

In the interior of Langara Island, Norway rats occur primarily in areas where shrub cover is high, and particularly where salal provides this cover. The dense salal thickets provide both shelter and food. Red huckleberry, on the other hand, likely provides only

food, because its growth form offers little shelter. These areas of dense shrubs shade the ground and suppress plant growth in the herb layer. Hence, rats are associated also with areas of low or absent herb cover. The rats' positive association with salal likely contributed to their negative association with western hemlock. Salal grows in dense thickets and likely excludes hemlock (Pojar and Mackinnon 1994).

Knowledge of the uneven distribution of rats throughout the island permits the allocation of baiting levels that are proportional to the probability of finding rats at each station. In the eradication program, coastal stations received 12 baits and interior stations received 6 baits (Taylor 1993, Kaiser *et al.* in prep.). Using my habitat association data, the coastal stations would continue to receive 12 baits, whereas the interior stations would receive 6 baits if salal grew in the surrounding area, and 3 or fewer baits if salal was not present. While such a scheme might increase complexity of field procedures, it would minimize use of poison bait, particularly in open bogs in the interior of the island. This deployment of poison baits would greatly reduce exposure for non-target species. The risk of undermining the eradication campaign excludes any areas from receiving no bait, even those areas where the likelihood of rats being present is very low.

CHAPTER 4

EFFICACY OF THE ERADICATION CAMPAIGN

Introduction

The Canadian Wildlife Service ran a pilot eradication project on Lucy Island during the summer of 1994. The intent of the pilot project was to test the New Zealand technique and to identify operational problems. During follow-up snaptrapping on Lucy Island in late August and November 1994, 1 juvenile male Norway rat was caught (Buck 1995). However, rat populations, like most small mammal populations, experience high mortality in the fall (Wirtz 1972, Moors 1985b, Moller and Craig 1987), and thus the remnant population might have disappeared from Lucy Island over winter. Additional snaptrapping was necessary in spring 1995 to determine if rats had been eradicated from Lucy Island.

Follow-up snaptrapping forms part of the protocol to confirm the effectiveness of an eradication campaign (Taylor 1993). I used this protocol to assess the efficacy of eradication efforts on Langara Island by comparing capture rates of rats and shrews in snap traps before and after the poison was deployed. I also compared evidence of rat feeding on apples before and after the eradication, and livetrapped rats in the Ancient Murrelet colony to provide Minimum Number Known Alive (MNA) and Jolly-Seber population size estimates (Ritchie and Sullivan 1989, Pollock *et al.* 1990, Krebs 1991, Mahon 1994) for the initial portion of the eradication campaign.

Methods

Lucy Island pilot project

In April 1995, 2 snap traps were placed near each bait station and in locations which showed evidence of rat activity. In total, 82 traps covered the entire island in 3

lines. In early June of 1995, 32 traps were set on Lucy Island, 2 snap traps at each bait station on the south side of the island and at other locations deemed most likely to have rats. All traps were set and baited with a mixture of peanut butter and oats and checked daily for 3 nights.

Livetrapping on Langara Island

Two parallel traplines were placed in the seabird colony within 50 m of the shore. The main trapline consisted of 30 Tomahawk live traps spaced 25 m apart, and the other line of 9 Tomahawk traps ran parallel 25 m further inland. The live traps were first set in the evening of July 7, 1995 and checked twice every 24 h (in the morning and in the evening) for 9 consecutive days, with the exception of July 14. Each captured rat was anaesthetized, marked with a numbered ear-tag, weighed, sexed, and released at the point of capture.

I used MINIMUM software to calculate MNA estimates, which serve as conservative measures of population size (Krebs 1991). Jolly-Seber population size estimates were calculated using JOLLY software by fitting the data to a constrained model which allowed for death but no emigration (Pollock *et al.* 1990). Morning and evening trapping sessions were grouped together to construct a series of 9 trapping occasions.

Snaptrapping on Langara Island

I used the snaptrapping lines that were established in May 1995 to test the efficacy of the eradication campaign. These traplines were set for 2 sessions at all 6 sites, and each session lasted 3 trap nights. The first session began in early August, during which bait stations dispensed the initial bait load. The second session began in late August, when bait removal had dropped to zero. At this time, the poison baits had been placed in plastic bags and the number of bait blocks reduced in number in the bait stations. Capture rates were analysed using the methods described in Chapter 3.

Apples as indicator baits on Langara Island

In late August 1995, a few days after the baits had been placed in plastic bags, 24 halves of apples were placed at 4 sites on Langara Island, 6 apples at each site. Two of these sites were in the seabird colony and 2 near Hazardous Cove. These apples were left out for 2 days and checked daily for feeding sign as described in Chapter 2.

Results

Lucy Island pilot project

During 246 trap nights, no rats were trapped on Lucy Island in April 1995 (Table 6), although the remains of 1 rat were found in a snap trap that must have been overlooked in November 1994. During this same period, 10 dusky shrews were caught. The second trapping session in June (96 TN) yielded 1 dusky shrew and 1 adult male Norway rat (289 g).

Livetrapping on Langara Island

During the 9 days of livetrapping between July 8 to 16, 57 Norway rats were caught, of which 45 were juveniles. No adults were recaptured, whereas 42% of the juveniles were recaptured at least once. The adults were not included in the calculations of the Jolly-Seber estimates of population size, because mortality estimates would be confounded with trap aversion. Estimates of population size from the recaptured juveniles ranged from 24 to 30 rats for 3 days, and then declined to 0 by July 16, the ninth day of trapping and 8 days after commencement of the poisoning campaign. Capture of new animals ranged from 4 to 14 rats per day for the first 6 days and then dropped to 0 on the eighth day of trapping (Fig. 10).

Table 6. Capture rates of Norway rats (*Rattus norvegicus*) and dusky shrews (*Sorex monticolus*) during 2 sessions of snaptrapping in 1995 following the rat eradication project on Lucy Island, Queen Charlotte Islands, British Columbia, in 1994.

Dates	Number of traps	<i>Sorex monticolus</i>		<i>Rattus norvegicus</i>	
		Number captured	C/100 TN	Number captured	C/100 TN
April 21-24, 1995	82	10	4.1	0	0.0
June 3-5, 1995	32	1	1.0	1	1.0

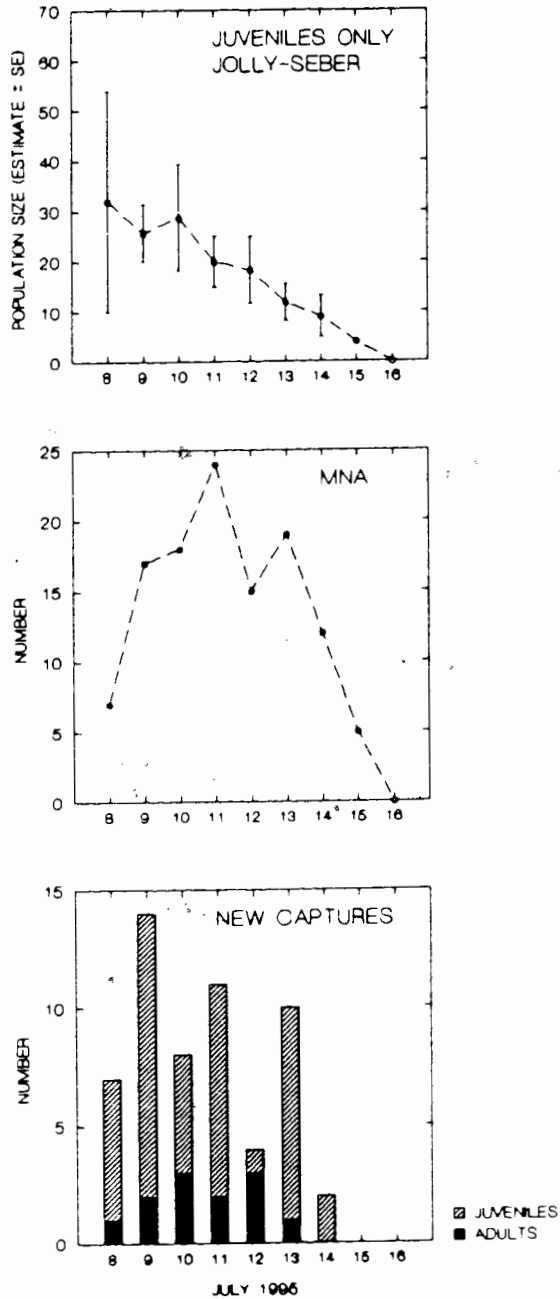


Figure 10. Jolly-Seber population size estimates, minimum number known alive (MNA) and number of new captures of Norway rats (*Rattus norvegicus*) during an eradication campaign beginning July 9, 1995. Estimates are based on mark-recapture data of rats trapped in the Ancient Murrelet colony on Langara Island, British Columbia.

Snaptrapping on Langara Island

Capture rates for both Norway rats and dusky shrews dropped dramatically in early and late August (Fig. 11). Rats were not captured during either trapping session in August in any sampling area. Capture rates for shrews declined from 5.8 C/100 TN in June and July to 1.7 ± 0.89 C/100 TN by early August (Student-Newman-Keuls test, $P < 0.05$). It then rose to 2.9 ± 0.89 C/100 TN in late August. The rate of sprung traps at each trapping site also dropped significantly (Student-Newman-Keuls test, $P < 0.05$), from 8 incidences per 100 TN before the poisoning campaign to 1.1 ± 0.51 incidences per 100 TN in early August and to 1.8 ± 0.5 incidences per 100 TN in late August.

Apples as indicator baits on Langara Island

Incisor marks of rats were not found on any apples set out in August (48 apple-nights). The average frequency of apples fed on by rats decreased from 2/10 apples in July to 0 during August.

Discussion

The Norway rat trapped on Lucy Island in April 1995 may indicate that the pilot eradication attempt was unsuccessful. The rat found in the snap trap left over from September 1994 raises the count to 2 rats trapped in the same season as the eradication. The rat trapped in June 1995 might have dispersed from Langara Island, although it likely survived the 1994 poison campaign. This was an adult, too old to be a dispersing juvenile. Buck (1995) attributes the failure to premature placing of baits into plastic bags. In the successful New Zealand campaigns, the speed of eradication depends largely on the

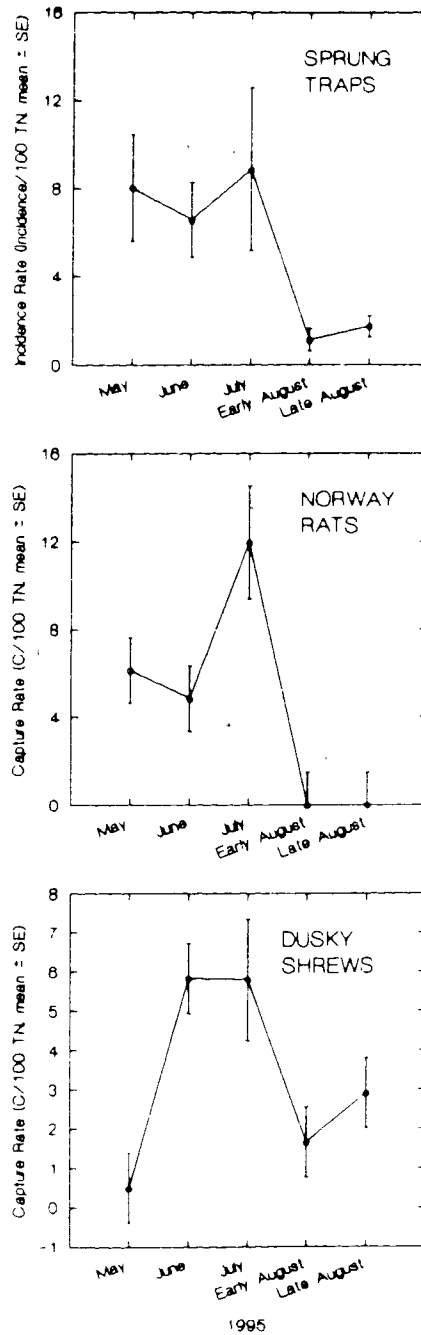


Figure 11. Capture rates of Norway rats (*Rattus norvegicus*) and dusky shrews (*Sorex monticolus*) in snap traps on Langara Island, British Columbia, in 1995. The eradication campaign began on July 9, 1995. Sprung traps, an index of activity, are traps that set off during the trapping period and failed to trap an animal.

baiting level, where the number of days to 99% bait-take declines with the number of baits available per ha per day (Taylor 1993). Following this pattern, baiting at 3-4 baits per ha per day, as was done on Lucy Island in July 1994, should result in 40-50 days to 99% bait-take. The baits were placed in plastic bags on day 19 of the campaign. This likely deterred the remnant neophobic rats from taking more bait (Buck 1995).

The change in capture rate of shrews on Lucy Island likely resulted from the shift of trapping from the north side of the island in April (where 9 of 10 shrews caught) to the south side of the island in June.

The low capture rates of shrews on Langara Island during the trapping session in May likely resulted from a combination of low densities of shrews and their small size. Juvenile shrews weigh < 4 g during spring and may not be heavy enough to set off the traps (Vanessa Craig, Faculty of Forestry, University of British Columbia, pers. comm.). In contrast, the reduced number of Norway rats on Lucy Island following the pilot eradication project may have increased exposure of shrews to the snap traps, explaining the high capture rates on Lucy Island in April. The precipitous decline in capture rates of shrews on Langara Island during August (Fig. 11) likely resulted from poisoning mortality. It is unlikely that an increase in availability of natural foods would have been sufficient to draw them away from the snap traps.

By all indications, the attempt to eradicate Norway rats on Langara Island was successful. No rats were caught after the poisoning in any of the sample areas, providing evidence of a dramatic drop in density. The absence of rat incisor marks on the apples, extremely sensitive indicators of rat presence, further attest to an absence of rats. The average number of sprung traps on each trapline also dropped significantly, suggesting reduced activity in all the sample areas.

Using the lines of snap traps to test the efficacy of the eradication campaign has three possible limitations. The first, as made evident by the low capture rates in the seabird colony while the birds were breeding, stems from the rats' tenacity for the principal available food source. Thus, the presence of the poison baits might also deter rats from approaching the traps. However, the lack of incisor marks on the apples provides evidence that the capture rates of rats in snap traps truly represented rat numbers. Furthermore, the successful captures of the second livetrapping session, which used peanut butter as bait, demonstrates that the rats approach the traps during the poison baiting.

The second limitation involves the lack of an available control site (i.e., a similar island where no poisoning occurred). All nearby islands had to receive treatment to ensure the integrity of the campaign. The presence of red squirrels (*Tamiasciurus hudsonicus*), black bears (*Ursus americanus*), and short-tailed weasels (*Mustela erminea*) undermined the usefulness of Graham Island as a control site. However, both the demise of 19 radio-collared rats and 36 rats found dead above ground during the eradication campaign indicate that poison was the main factor causing the observed decrease in detection and capture rates of rats (Gregg Howald, Department of Animal Science, University of British Columbia, pers. comm.).

The third limitation is that snaptrapping kills the animals. Hence, the observed decline in capture rates might have resulted from the snaptrapping itself. However, repeat snaptrapping did not result in reduced capture rates between May and June at any snaptrapping site, suggesting that snaptrapping did not remove a significant proportion of the population. Snap trapping can thus serve as a reliable index of population size.

The major criteria to determine the number of visits (N) required for statistical confidence of inferring the absence of a species are species detectability (p) and the desired probability of a Type I error (α level) (Reed 1996). N is calculated as:

$$N = \frac{\ln(\alpha \cdot level)}{\ln(1 - p)}$$

Because I had no independent measure of detectability, I calculated detectability using the number of traplines where at least 1 rat was caught divided by the total number of trapping lines prior to the eradication campaign. This provided a rough estimate of detectability for 3 nights of snaptrapping which ranged from 1.0 near the coast and 0.9 in the interior habitats. Thus, the 2 trapping sessions following the onset of the eradication campaign during which no rats were caught are adequate to conclude that rats are absent at an α level of 0.05. However, I derived these estimates of detectability when rats occurred at high densities, and they may not apply at lower rat densities. At low levels of detectability (e.g., $p = 0.2$), 14 independent snaptrapping sessions are needed to provide the same level of statistical confidence in concluding rats are absent from the island. Furthermore, this approach also assumes the snaptrapping sites represent the entire island. These sites did not include the areas of human habitation.

Since the poison baiting operation during the summer of 1995, LISHRP personnel have systematically checked the bait stations 3 times, during September 1995, April-May 1996, and July 1996. The clearest signs of rat activity have involved the 2 areas of human housing on the island: the fishing lodges and the lighthouse. In September 1995, checking of all the bait stations revealed that bait had been removed from 7 stations around Henslung Cove. This area contains the shore installations for the fishing lodges which may have provided food for the rats during the poisoning campaign. The rats associated with human habitation likely began to forage more widely when these facilities closed at the end of the summer. Subsequent re-baiting in September 1995 resulted in the taking of 17 more baits, but rat activity has not occurred since. In January 1996, the lighthouse keepers trapped a juvenile male rat. This rat and perhaps others apparently survived the July campaign by feeding on a grain store at the lighthouse. Eight additional bait stations were placed near the lighthouse, but no further rat activity was observed.

During the checks of bait stations in April-May and July 1996, large numbers of bait stations, 289 and 176 respectively, were found disturbed in a similar manner. This included uprooting of the entire bait station, removal of lids, and removal of baits, bags and aluminum trays (intended to keep the baits dry). Several signs indicate that Common Ravens (*Corvus corax*) were responsible, including triangular impressions the shape and size of a raven's beak on the aluminum trays. Disturbed baits did not have incisor marks characteristic of Norway rats. Furthermore, dead ravens were found, along with blue-coloured feces and pellets containing blue wax and parts of plastic bags. In July and August of 1996, LISHRP personnel inserted bamboo skewers across the openings of the stations in an effort to prevent further raiding of the bait stations by ravens. Plans for the future include 1 more check of all the bait stations on the island, subsequent re-baiting if needed, and a cleanup operation.

CHAPTER 5

MODIFICATION OF BAIT STATIONS

Introduction

The eradication campaign placed the population of dusky shrews of Langara Island at risk of local extinction. Furthermore, in the fall of 1994, a survey crew found 1 male deer mouse on Langara Island. This animal might represent a remnant population, although it may have been brought over during the survey crew's frequent trips from Graham Island. Both species would have direct access to the poison baits in the stations. Given the natural endemicity of small mammal populations in the Queen Charlotte Islands (Foster 1965), and the nature of the project as a habitat restoration project for native species, local extinction of dusky shrews and deer mice must be prevented. One way to reduce their exposure to the poison would be to modify the bait station and deny them access to the baits (Buck 1995). The modifications must be simple; the large number of bait stations (~4000) would make complex modifications impractical and likely financially prohibitive.

Methods

Two modifications were tested: (1) the bait stations were raised 6 cm above the ground using blocks of wood; and (2) the bait stations had both ends capped with a half-moon shaped piece of plastic so that shrews could not climb into the bait station. I used 2 approaches to examine the efficacy of these modifications in denying shrews access to bait stations. The first involved a series of tracking boards, and the second involved behavioural observations of live-trapped shrews within an enclosure.

Tracking boards

Three lines of unbaited stations were established, 1 line in each of the 3 main habitat types: Sitka spruce, hemlock and redcedar. Each line spanned 270 m and had 18 stations spaced 15 m apart. Tracking boards were placed inside the stations which were baited with dried fruit and peanut butter suspended over a shallow dish filled with tracking powder. Each station received 1 of 3 treatments: control, capped or raised. The stations were arranged such that each control station was bracketed by 1 of the treatment stations. All the stations were checked and re-baited daily for 3 days. At each check, the number and species of different sets of tracks were recorded.

I analyzed the frequency of shrew tracks on the tracking boards by modeling the conditional probability of a board having a shrew track as a function of a series of variables and their interactions. The variables were treatment (raised, capped or control), habitat (spruce, hemlock or redcedar), day (1, 2 or 3) and rat track (present or absent). Using rat track as an independent variable assumes a one-way interaction between rats and shrews. Rats were able to remove all the bait in 1 visit to the bait stations, whereas shrews could not.

In general, the probability model had the form:

$$\Pr(\text{track} | x) = p = \frac{e^x}{1 + e^x}$$

with the logit line,

$$x = \log(p/(1-p)) = \alpha + \beta_1 \text{ treatment} + \beta_2 \text{ habitat} + \beta_3 \text{ day} + \beta_4 \text{ rat track}.$$

Using SAS (PROC GENMOD) to derive estimates of the parameters, I tested a hierarchy of models. I began with the main effects model and compared it to a model which included all first order interactions. This was followed by sequentially eliminating each interaction and main effect variable which did not significantly contribute to the model,

thus obtaining the most parsimonious list of variables needed to model the data. The likelihood ratio test (LRT) was used to assess the contribution of each excluded parameter to the model. This test involves calculating the deviance for each model. The deviance of the model is a goodness-of-fit statistic based on the loglikelihood function given by $-2 \ln(\text{likelihood})$ (SAS Institute 1990a). It is analogous to the Sum of Squares in linear regression. The difference in deviance between two models, one with and the other without the parameter of interest, tests the hypothesis that the excluded parameter is equal to zero. The LRT has a chi-square distribution with the degrees of freedom equal to the difference in the number of estimable parameters between the two models (Trexler and Travis 1993).

I also calculated Akaike's Information Criterion (AIC) for each model to aid in model selection. This measure was defined as:

$$\text{AIC} = \text{Deviance} + 2 \times (np - r)$$

where, np = number of parameters and r = the number of response values (SAS Institute 1990b). Selecting models with the lowest AIC corrects for the increasing lack of reliability of individual parameters which results from increasing the number of parameters in a given model (Lebreton *et al.* 1992).

Goodness-of-fit between the predicted and observed observations was assessed using the deviance statistic, which is distributed as a chi-square with $J - (np + 1)$ degrees of freedom and can be used to test the hypothesis that the fitted model is adequate (Trexler and Travis 1993). J is the number of distinct combinations of all independent variables and np is the number of parameters in the model.

Behavioural observations

Six shrews were livetrapped using small Sherman aluminum traps. For each trial, 1 shrew was placed in a 2 × 2 m confined testing arena. After a 5 min acclimation period, a baited unmodified station was placed inside the enclosure and left until the shrew was seen to enter it. The shrew was then gently expelled from the station and the station removed and replaced by a modified station (i.e., either raised or capped). After 5 min, this first modified station was removed and replaced by a station with the other modification. I recorded the length of time the shrew took to enter each station.

Results

Tracking boards

On average, shrews entered 1.3 of the 18 capped bait stations during each night of the experiment, whereas shrews entered 3.3 of the 18 control and raised bait stations during each night (Fig. 12). This difference however is not statistically significant. The most parsimonious model (Model 8) that explains the probability of finding shrew tracks does not include treatment type as a significant explanatory factor (Table 7). Furthermore, the LRT's comparing models which include and do not include treatment type detected no significant difference between them (LRT 2 & 8).

The most parsimonious model includes habitat and the presence of rat tracks as significant explanatory variables, for which the latter variable provides the strongest result. I found fewer shrew tracks in bait stations having rat tracks than in bait stations without rat tracks (Fig. 12).

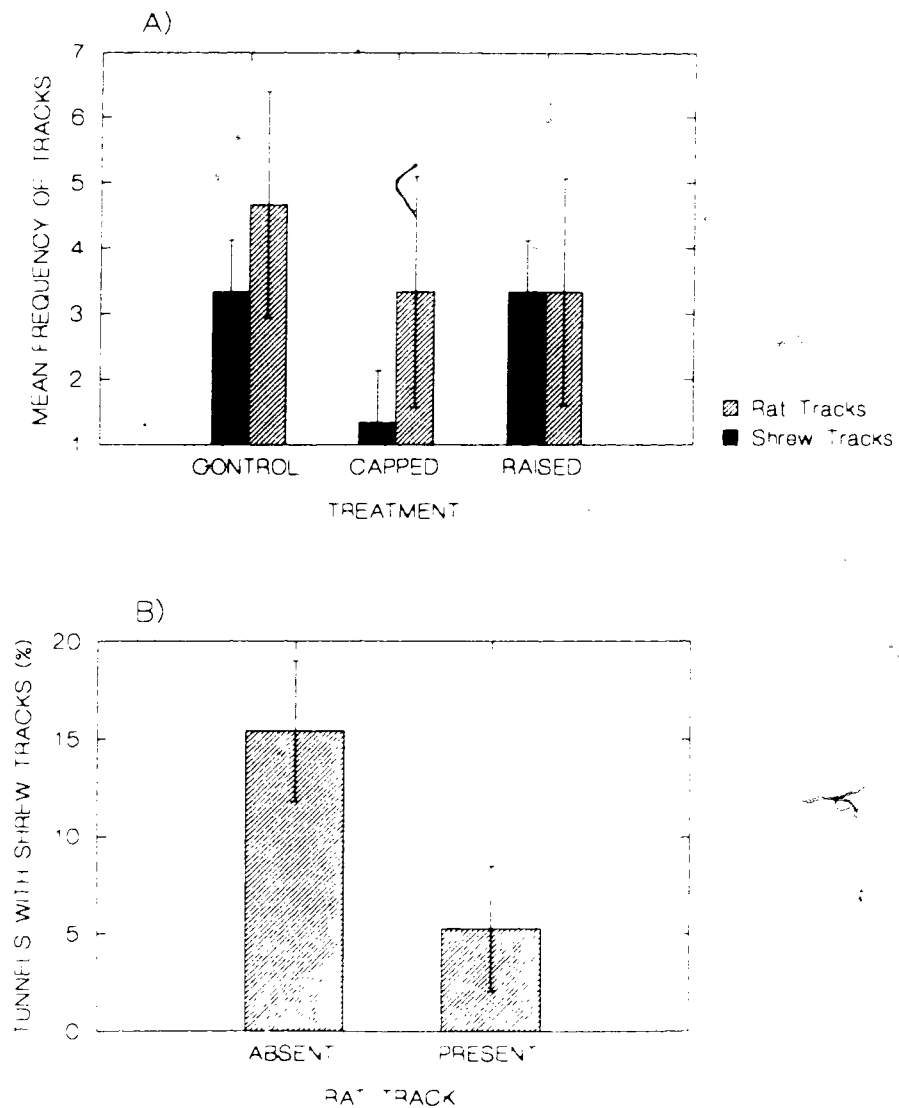


Figure 12. A) Mean frequency of rat (*Rattus* spp.) and shrew (*Sorex* spp.) tracks in bait stations modified to prevent the entry of dusky shrews (*Sorex monticolus*) on Langara Island, British Columbia. Frequency of tracks is the number of 18 bait stations in each treatment which had rat or shrew tracks after 24 hours. SE for 3 nights are shown on the bars. B) Percent of stations with shrew tracks with and without rat tracks.

Table 7. Model selection procedure for bait station modification experiment. a) *DF*, degrees of freedom; *NP*, number of estimable parameters; *AIC*, Akaike's information criterion. b) *LRT*, likelihood ratio test; Δ *DEV*, difference in deviance; Δ *NP*, difference in number of estimable parameters. See text for definitions.

a) Models examined:

Model	Parameters	Deviance	DF	P	NP	AIC
1	Habitat, treatment, day, rat, and all first order interactions	110.512	142	0.98	16	138.512
2	Habitat, treatment, day, rat	119.957	155	0.98	7	129.957
3	Habitat, day, rat	124.140	157	0.98	5	130.140
4	Treatment, day, rat	123.662	157	0.98	5	129.662
5	Habitat, treatment, rat	120.906	156	0.98	6	128.906
6	Habitat, treatment, day	123.709	156	0.97	6	131.709
7	Rat	129.711	160	0.96	2	129.711
8	Rat, habitat	125.124	158	0.98	4	129.124

b) Likelihood ratio tests:

LRT	Models compared	Δ DEV	Δ NP	P
1	1,2	9.445	9	0.40
2	2,3	4.183	2	0.12
3	2,4	3.705	2	0.16
4	2,5	0.949	1	0.33
5	2,6	3.752	1	0.05
6	2,7	9.754	5	0.08
7	7,8	4.587	2	0.10
8	5,8	4.218	2	0.12

Behavioural observations

Within 3-5 min of entering the testing arena, all 6 shrews were able to enter control, raised and capped stations with equal ease by jumping directly into the opening, or by climbing in from above after jumping on top of the bait station.

Discussion

The lack of significant differences in the frequency of shrew tracks among treatments likely occurred because the relative sizes of the proportions are small. Shrews tracks occurred in 1.33 out of 18 bait stations (7.4%) with the capped treatment, compared to 3.33 of 18 bait stations (18.5%) with the control treatment. Power for LRT 8 that compared models which include and do not include treatment type was 0.41. With the given sample size, only differences of 20% occurrence among the treatments would be detectable at the recommended power of 0.80. Thus, because of low statistical power, I cannot state unequivocally that the probability of finding shrew tracks in the bait stations does not depend on treatment type.

Shrews could enter both types of modified bait stations in the testing arena with equal ease. Conditions in the testing area do not mimic conditions in the field. Capture stresses the shrews and they have no other cover available to them. Perhaps, the experiment forces shrews to enter the stations more than they would in the field. Nonetheless, this is evidence that shrews can enter the modified bait stations. However, support for the capped treatment comes from the biology of shrews. Shrews forage primarily by smell (Nagorsen 1996), and the cap might reduce the size of the odour plume exuding from the station. Shrews may enter the capped stations with reduced frequency because they cannot detect the presence of bait.

The strongest result comes from the negative relationship between frequency of shrew tracks and presence of rat tracks. This can result from active exclusion by rats, or

by rats taking the bait and thus removing the impetus for shrews to enter stations, or by obstruction of shrew tracks by the larger rat tracks. Although such error is possible, I found shrew tracks with rat tracks on 2 occasions, which attests to my ability to discern individual tracks. The negative correlation suggests that in areas of high rat densities, rats will deny the shrews direct access to the poison. Thus, the shrews' exposure to the poison will be a function of the time that the baits are left in stations after the majority of rats are killed.

GENERAL DISCUSSION AND CONCLUSIONS

I examined the diet, distribution and habitat use of Norway rats on Langara Island, British Columbia, to provide information relevant to an eradication effort conducted to restore breeding habitat for Ancient Murrelets. My objectives were to: 1) describe the diet of Norway rats using stomach content analyses and stable isotope composition of liver tissue of rats; 2) compare methods to monitor the presence and density of Norway rats; 3) describe their distribution and habitat use on Langara and its associated islands; 4) assess the efficacy of the eradication campaign; and 5) examine the utility of 2 modifications to bait stations for their ability to exclude shrews.

I determined the diet of Norway rats on Langara Island by examining stomach contents and concentrations of stable isotopes in the livers of 80 rats snaptrapped during May and July, 1995. Foods occurring with high frequency and in high volumes were plant shoots, salal berries, tissues of Ancient Murrelets, amphipods, Sitka spruce seeds, and fungi. I found no differences in diet between males and females, although the frequencies and volumes of food groups in stomachs varied with region and habitat in which rats were trapped. Ancient Murrelets occurred in high volumes in 53% of stomachs from rats trapped in the Ancient Murrelet colony. This implicates Norway rats in the decline of Ancient Murrelets on Langara Island. Plant shoots and terrestrial invertebrates occurred more frequently in the diet of rats from the interior of the island than in the diet of rats from near the coast, whose diet consisted primarily of marine invertebrates and fruits and seeds. The livers of rats from the Ancient Murrelet colony had $\delta^{15}\text{N}$ values averaging 16.6 ± 1.1 ‰, indicating that they fed at a higher trophic level than rats from Hazardous Cove and South End, whose livers had mean $\delta^{15}\text{N}$ values of 13.7 ± 3.5 ‰ and 10.9 ± 3.3 ‰, respectively. The livers of interior rats had $\delta^{13}\text{C}$ values averaging -21.3 ± 0.8 ‰, indicating a lower contribution of marine protein in their diet than rats near the coast

which had $\delta^{13}\text{C}$ values averaging $-18.2 \pm 1.9 \text{‰}$. Norway rats appear to exploit the highest quality and most readily available food depending on the region and habitat.

Capture rates of Norway rats in the seabird colony during the Ancient Murrelet breeding season ranged between 0 and 0.5 C/100 TN, while concurrent capture rates at other regions of the island ranged between 2.2 to 17.1 C/100 TN for snaptrapping. Thus, the presence of breeding seabirds undermines the utility of trapping as a monitoring tool, particularly if Sherman aluminum traps are used. These traps had lower capture rates than did Tomahawk live traps used on the same grids. Radio telemetry and other research which involves trapping rats in the Ancient Murrelet colony must be done before or after the breeding season of the seabirds. Apples were a useful monitoring tool and detected the presence of rats in areas where they were not trapped.

Although Norway rats occur throughout Langara Island, they are not evenly distributed. The coastal habitat on Langara Island supports approximately 3 times the density of rats in the interior of the island. Within the interior of the island, rats are more likely to be found in areas having dense shrub cover provided by salal and red huckleberry than areas with sparse shrub cover. Future baiting programs could be modified to suit the distribution of Norway rats on islands such that areas of high rat density receive more bait per station than do areas where rats are less likely to be found. If the program on Langara Island were to be repeated, I recommend maintaining the baiting level of 12 baits around the coast, and 6 baits in areas of dense shrub cover in the interior of the island. Bait stations in areas with sparse shrub cover or no salal, such as the open bogs in the interior, should receive 1-3 baits. Such a scheme would complicate field procedures but would reduce the amount of bait used, thus reducing costs and exposure to non-target organisms.

Capture rates of shrews decreased significantly following the main baiting period, indicating some non-target poisoning of these animals occurred. Capture rates of shrews then rose after poison baits were placed inside plastic bags in the bait stations, indicating

the population can likely return to pre-baiting densities. Exposure of native small mammals to rodenticides might be reduced by modifying the bait stations. I tested raising and capping the bait stations and found no significant differences in frequencies of shrew tracks in modified stations relative to unmodified bait stations. Thus, neither modification offers a simple way to exclude shrews. However, the capped stations are promising and more research is needed. These stations likely have reduced odour plumes and are thus less attractive to foraging shrews.

The eradication of Norway rats on Kiisgwaii appears to have succeeded. No rats were trapped or observed in the sample areas following the poison campaign. No feeding by rats was found on apples, which serve as sensitive indicator baits, during 48 apple nights. Rats have been detected around the lighthouse and the fishing lodges, but no activity has been observed in those areas following baiting. No rat activity has been detected on Langara Island since January 1996.

Langara Island and its adjacent islands cover more than 3000 ha. An area this size will become valuable habitat for seabirds in British Columbia if it remains rat-free. The potential for reintroduction of rats remains the Achilles heel of the project and preventative measures must be taken. Parry Passage provides an adequate barrier for direct recolonization from Graham Island. The frequent barges and boats that travel to Kiisgwaii from areas supporting rats present the greatest risk of reintroduction. All vessels that intend on mooring on Langara Island must be inspected and certified to be rat-free. Barges carrying food must be inspected annually and safely baited with rodenticides. Rodenticides should be strategically deployed to avoid the development of resistance. The Coast Guard already has a plan in effect to prevent movement of rats through its food supply runs to the lighthouse. This plan should be rigorously enforced to all users of the island and surrounding moorages. A permanent ring of bait stations should be established around the areas of human habitation, perhaps using hoppers. A supply of bait stations

and rodenticide should be left on the island to allow for rapid response to signs of rat presence. Owners of the fishing lodges could be encouraged to cooperate by informing them of the economic value of intact seabird colonies for ecotourism. Periodic monitoring of rats should continue for 2 more years. This should include the use of snap traps and more sensitive indices such as chew sticks and fresh apples. The status of the population of Ancient Murrelets should be monitored. In particular, mortality and rates of population change of Ancient Murrelets should be determined. This will be the definitive measure of the success of the eradication campaign.

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