Ecology of Coastal Raccoons (*Procyon lotor*) on the Queen Charlotte Islands, British Columbia, and Evaluation of Their Potential Impact on Native Burrow-nesting Seabirds

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ABSTRACT

This three-year study investigated the potential impact of introduced raccoons (*Procyon lotor*) on native, burrow-nesting seabirds of the Queen Charlotte Islands (QCI). Raccoon diet, home range size, and patterns of movement and activity were documented on Vertical Point (VP), Louise Island, where no seabirds breed, and on adjacent East Limestone Island (EL), site of an Ancient Murrelet colony containing roughly 1,215 breeding pairs. Spring-summer diet was compared between these locations based on fragment counts of scats collected biweekly along 300 m shoreline latrine circuits, from VP (n=55) and EL (n=12). Intertidal invertebrates, particularly shorecrab (*Hemigrapsus nudus*) and amphipods, occurred in all VP scats, and comprised 92% of the total fragment count, whereas they occurred in only 57% of EL scats, and comprised 20% of the total fragment count. Seabird remains were absent from VP scats, but occurred in all EL scats, comprising 43% of the fragment count.

Home range, movement and activity patterns were determined using telemetry and direct observations. Five males (M) and 4 females (F) were located a total of 614 times, divided between day and night. Four animals (2M, 2F) were intensively monitored for two summer field seasons, the remaining five for one. Data obtained for 2 raccoons from EL (1M, 1F) were compared with data for animals on VP. Single season, 100% minimum convex polygon home ranges on both VP and EL ranged from 32.0 - 96.6 ha for males (X +/- S.D. = 60.2 +/- 23.0 ha), and from 17.1 - 39.5 ha for females (X = 28.3 +/- 8.3 ha). Home ranges included 1,825 to 6,245 m of shoreline. Home ranges overlapped both between and within sexes. The ability of raccoons to survive within small home ranges, and their non-territorial behaviour, contribute to their ability to persist on small islands.

Raccoons were primarily nocturnal, inactive for 75% of day locations, and active for 93% of night locations. Daily denning usually occurred within 150 m of shore, and up to a maximum of 750 m inland. Active locations were concentrated on the shoreline at VP, but occurred both on the shoreline and within the boundaries of the seabird colony on EL. The nocturnal behaviour of raccoons and their association with the shoreline bring them in contact with breeding seabirds, and their activity within the colony indicates a response to seabirds. Raccoon predation on seabirds was characterized and measured using site investigations, predation transects and carcass monitoring. Eleven of 15 site investigations tied active raccoon locations to recent evidence of predation on seabirds, which included dug burrows, broken eggs and single or multiple headless carcasses. Predation levels were estimated by walking 7, 20-m-wide belt transects (17% of colony area) every 3 days, from April 9 to June 8 1991. Six headless carcasses, 77 feather piles, 30 broken eggs, 2 chicks and 12 dug burrows were found on the transects, representing the loss of approximately 488 adults and 188 juveniles. Extrapolation of carcass numbers, corrected for losses due to scavenging, yielded an estimated 252 breeding and non-breeding adults killed by raccoons during the period of study (approx. 1 seabird/raccoon/night). Losses due to raccoon predation likely exceed recruitment, and could cause substantial declines in colony size, or extinction of the colony.

I surveyed 61 islands in 1990 and 1991 for evidence of raccoons, using latrine and spotlight circuits. Raccoons have reached at least 35 of these islands, requiring over-water crossings of up to 950 m +/- 100 m. Thus, approximately 80% of all colonies and 75% of the burrow-nesting seabird population of the Queen Charlotte Islands are potentially at risk. The accessibility of many colony islands to raccoons, and the severity of raccoon predation on burrow-nesting seabirds, indicate a pressing need for monitoring and control efforts aimed at preventing the raccoon's colonization of seabird islands.

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TABLE OF CONTENTS

Study Area

Chapter 1. Diet of coastal raccoons of the QCI in the presence and absence of burrow-nesting seabirds

Chapter 2. Home range, movement and activity patterns of coastal raccoons of the QCI in the presence and absence of burrow-nesting seabirds

Chapter 3. Raccoon predation on burrow-nesting seabirds of the QCI

Chapter 4. Raccoon distribution and contact with burrow-nesting seabirds on the QCI

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

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Dedicated to my family.

(photo courtesy of Debra Murie)

GENERAL INTRODUCTION

Many of the world's islands have been subject to both accidental and deliberate species introductions by human beings. Such introduced, or alien species, have typically caused severe alterations to the original island ecosystems (Elton 1958). In particular, introduced mammalian predators have devastated island avifaunas, until recently ranking as one of the single greatest causes of island bird extinctions (Johnson and Stattersfield 1990).

Seabirds, which nest on islands, are highly vulnerable to introduced mammalian predators due to their low annual productivity, and lack of effective anti-predator behaviours (Furness and Monaghan 1987). Although mammalian predators are thought to have caused the complete extinction of only one seabird species, they have been responsible for numerous local extirpations, and reductions in the size, areal extent and breeding success of many other colonies (Moors and Atkinson 1984). Recognition of the threat posed by introduced mammalian predators has recently led to concern over the potential impact of introduced raccoons on the native, burrow-nesting seabirds of the Queen Charlotte Islands (QCI).

The raccoon is a medium-sized procyonid. Weights of adults typically range from 3.6 kg to 9 kg (Kaufmann 1982), with males slightly heavier than females, and animals from more northern latitudes heavier than those from the south (Sanderson 1987). The average life span in northern parts of their range has been estimated at 2 years (Sanderson 1951, Cowan 1973), but wild animals can survive up to 12 years (Haugen 1954, Cowan 1973). Although most males do not attain reproductive maturity until their second year, approximately half of all females breed successfully as yearlings (Sanderson 1987). Peak breeding occurs from February to March, depending upon latitude, and typically results in a litter of 2 to 5 kits following a gestation period of approximately 63 days (Sanderson 1987). The raccoon's life history characteristics, omnivory and limited number of predators all contribute to the species' ability to successfully colonize a wide range of habitats (Sanderson 1987).

The wide distribution of the raccoon attests to the versatility of the species. In North America, the raccoon's natural range extends across the continent, from Panama as far north as central Saskatchewan (Kaufmann 1982). Most of this range was colonized in the last century, during which time the population size of raccoons is thought to have increased by 15-20 times (Sanderson 1987). Successful introductions in North America include islands south of Alaska (Scheffer 1947) and off the Florida coast (Sherman 1954). In Europe, introduced raccoons have successfully colonized many countries. In the 1930's they were released in Russia (Aliev and Sanderson 1966) and Germany (Roeben 1975), where recent reports indicate an expanding range (Heidemann 1982, Hempke 1985, Borrmann and Hempke 1990, Lange 1990). Populations also have been recorded in France (de Beaufort 1968), Austria (Aubrecht 1985), the Netherlands (Hoekstra 1983), Hungary (Nechay 1987) and Poland (Bogdanowicz and Ruprecht 1987), and several sightings have now been reported in England (Howes 1990).

Consistent with its demonstrated ability to colonize new environments, the raccoon has survived and expanded its range on the QCI. Released in the early 1940's near Lawnhill, Graham Island, under the authority of the Provincial Game Commission, raccoons spread rapidly throughout the archipelago (Summers and Rodway 1988). The first description of their distribution, based on observations gathered by seabird researchers in the mid-1980's, indicated that they had expanded their range the length of the QCI. As the archipelago is roughly 300 km in length, and the point of introduction near its centre, this corresponds to a minimum rate of spread of approximately 4 km/yr "as the crow flies". If range expansion followed the highly dissected shoreline, the distance travelled, and hence rate of colonization, is greatly increased.

This range expansion has placed raccoons in increasing proximity to many colonies of breeding seabirds on the QCI. Approximately 150 colonies, containing over 1.5 million seabirds, are located on islands distributed along the length of the archipelago (Rodway et al. 1988). This represents almost half of all seabirds breeding in British Columbia (Kaiser and Lemon 1987). Of the twelve species present, the six burrow-nesters comprise 99% of the total population (Table 1). Of particular importance are breeding populations of Cassin's Auklet (*Ptychoramphus aleuticus*) and Ancient Murrelet (*Synthliboramphus antiquus*), which comprise 74% of the total seabird population of the QCI, and represent 30% and 70%, respectively, of the known world population of these species (Kaiser and Lemon 1987). Given the numerical importance of the QCI burrow-nesters, the increasing proximity of raccoons is of significant concern to seabird conservation.

Raccoons prey heavily on many ground-nesting species. Nest predation by raccoons has been documented for several species of birds (Llewellyn and Webster 1960, Bellrose et al. 1964, Urban 1970, Hjertaas 1982, Johnson et al. 1989, De Smet 1987), alligators (Joanen

Table 1. Estimated population size of seabird species breeding in the Queen Charlotte Islands.

SEABIRD SPECIES	ESTIMATED POPULATION[+]
Hydrobatidae	
Leach's Storm-Petrel (*Oceanodroma leucorhoa*)*, and Fork-tailed Storm-Petrel (*O. furcata*)*	312,800
Alcidae	
Ancient Murrelet (*Synthliboramphus antiquus*)*	542,900
Cassin's Auklet (*Ptychoramphus aleuticus*)*	600,700
Rhinocerous Auklet (*Cerorhinca monocerata*)*	74,360
Tufted Puffin (*Fratercula cirrhata*)*	1,850
Horned Puffin (*F. corniculata*)	30
Common Murre (*Uria aalge*)	440
Pigeon Guillemot (*Cepphus columba*)	5,090
Laridae	
Glaucous-winged Gull (*Larus glaucesens*)	5,180
Phalacrocoridae	
Pelagic Cormorant (*Phalacrocorax pelagicus*)	350
TOTAL	1,543,700

[+] from Rodway et al. (1988, 1990) and unpublished data of the Canadian Wildlife Service.

* burrow-nesting species

1970, Fleming 1971), and various species of turtle (Shabica et al. 1978, Burger 1977, Davis and Whiting 1977, Stancyk et al. 1980, Christiansen and Gallaway 1984, Christens and Bider 1987, Kushlan 1986, Franz 1986, Wilhoft et al. 1979, Hopkins et al. 1978). Such nesting losses have frequently exceeded 50%, and have at times accounted for the complete breeding failure of local populations. Predation on young muskrats (*Ondatra zibethica*) (Wilson 1953, Errington 1967) and rabbits (Atkeson and Hulse 1953) also has been documented.

The documented success of raccoons in colonizing new environments and preying upon ground-nesting species clearly suggests that they could threaten burrow-nesting seabirds on the QCI. Our ability to evaluate the extent of this threat has been hindered, however, by a lack of information on the basic ecology of raccoon's in this region, and their behaviour when on colony islands. Many studies of raccoon ecology have been carried out in the eastern United States, including Alabama (Johnson 1970), Kansas (Stains 1956), Michigan (Stuewer 1943), Tennessee (Tabatabai 1988), Wisconsin (Downey 1954), New York (Van Dwarf 1971), and North Dakota (Frieze 1976), and Cowan (1973) studied raccoons in southwestern Manitoba. However, there are no detailed studies from the northern, coastal part of their range.

Evaluating the potential impact of raccoons on burrow-nesting seabirds of the QCI hinges on consideration of three major factors: a) the capability of raccoons to persist on islands with breeding seabirds, b) the magnitude of their predation on seabirds, and c) the probability that raccoons reach colony islands. Evaluation of these factors depends upon an understanding of the ecology of raccoons in both the presence and absence of breeding seabirds, and of characteristics of the distribution of both raccoons and seabirds in the QCI.

The ability of raccoons to persist on seabird colony islands depends upon how well they meet their basic requirements for survival, specifically food, water, shelter and space. Breeding seabirds are present not on the largest islands of the archipelago, but on the numerous smaller, adjacent islands. Furthermore, they are present for only a few months of the year. The distribution and abundance of the raccoon is therefore largely dictated by conditions in the absence of seabirds. In Phase I of this study, diet and home range characteristics of raccoons were documented in an area devoid of seabirds, both to identify basic requirements and to provide baseline data for comparison with observations made in the presence of seabirds.

For those colony islands capable of supporting raccoons, it is necessary to know whether and to what extent raccoons prey on breeding seabirds. In Phase II of the study, I investigated the ecology of raccoons on an active colony island. The response of raccoons to the concentrated, but ephemeral, food supply represented by seabirds was examined indirectly and directly. Diet and home range characteristics documented on the colony were compared with those documented in Phase I, to identify any shifts associated with the presence of breeding birds. In addition, predation by raccoons was described and quantified to evaluate the long-term outcome of their interaction with seabirds.

Identifying the probability that raccoons come in contact with breeding seabirds hinges on information concerning the raccoon's distribution in the archipelago, relative to seabird colonies. In the third and final phase of the study, surveys were carried out to identify islands currently occupied by raccoons and islands which, on the basis of the species' current distribution, are at risk of colonization.

To address these three factors, the following objectives were established for this project:

a) to describe the diet of raccoons in the presence and absence of breeding seabirds (Chapter 1),

b) to describe the home range, movement and activity patterns of raccoons in the presence and absence of breeding seabirds (Chapter 2),

c) to quantify the level of predation by raccoons on breeding seabirds (Chapter 3),

d) to document the distribution of raccoons on the QCI in relation to islands with seabirds (Chapter 4), and

e) to evaluate the threat posed by raccoons to burrow-nesting seabirds, and offer management recommendations (Chapter 5).

DESCRIPTION OF STUDY AREA

Queen Charlotte Islands

Physical Environment

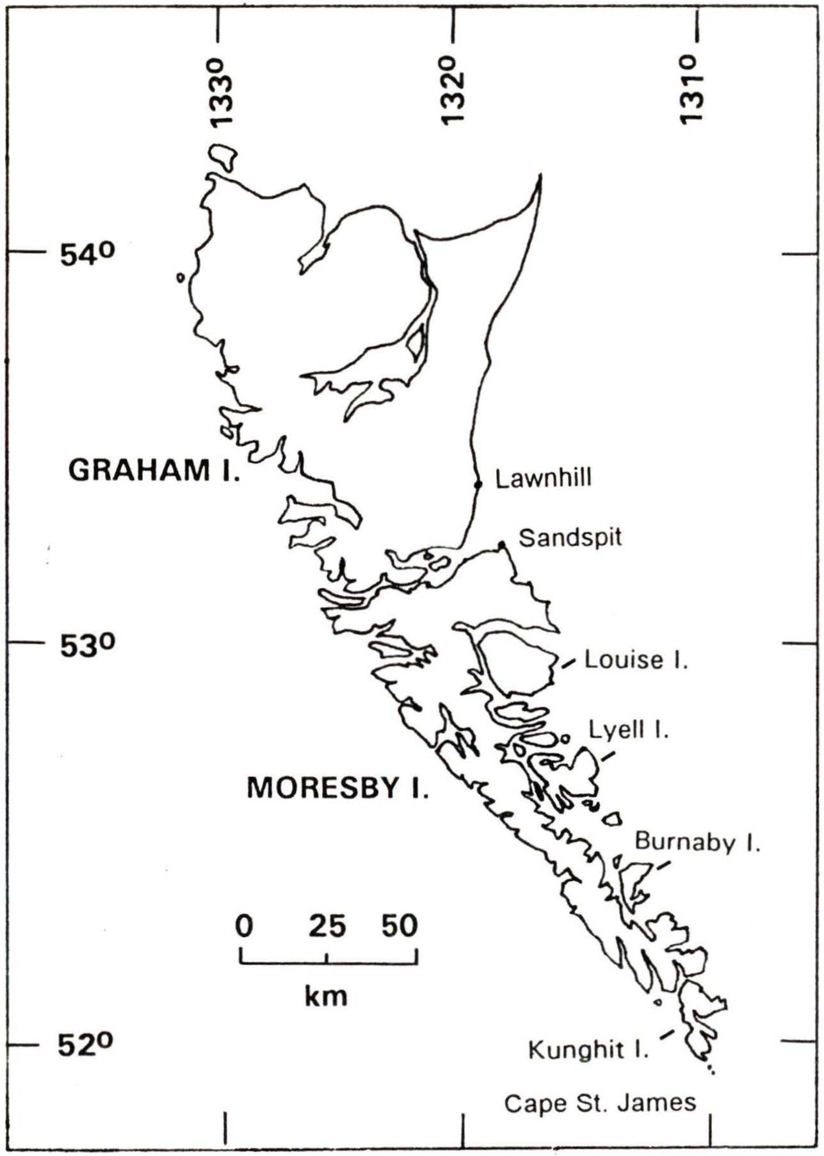
The Queen Charlotte Islands, traditionally called Hadean Gwaii, is an archipelago of approximately 150 islands, located 80 to 150 km off the west coast of British Columbia (Fig. 1). The archipelago is 300 km long, and 100 km at its greatest width. The bulk of the land mass consists of the two largest islands, Graham and Moresby, which span almost the entire length of the archipelago, and are separated by less than 50 m at their closest point. Other islands of substantial size include Louise (27,192 ha), Lyell (17,452 ha), Burnaby (6,596 ha) and Kunghit (12,987 ha).

Holland (1976) divided the QCI into three physiographic regions: the Queen Charlotte Ranges, Skidegate Plateau and Queen Charlotte Lowland. The Queen Charlotte Ranges form the mountainous backbone of the region. They extend the length of the archipelago along its western side, and reach a maximum elevation of 1110 m (Holland 1976). The Skidegate Plateau, a broad strip of land of less rugged topography, abuts the northeast half of the Ranges. The Queen Charlotte Lowland, an area of limited relief, occupies the northeastern corner of Graham Island and reaches a maximum altitude of approximately 300 m.

The QCI have a humid, temperate climate, characterized by warm, wet winters and cool summers. Data recorded at Sandspit from 1951-80 (Environment Canada 1985) illustrate climatic conditions, although conditions are wetter and windier on the exposed west coast, and cooler at high elevation inland sites (Calder and Taylor 1968). Average temperatures range from 2.0 C in January (mean max. 4.5 C; mean min.-0.4 C) to 14.7 C in August (mean max. 17.6 C; mean min. 11.9 C), one of the narrowest annual ranges in Canada (Farley 1979). Winter temperatures are mild, and prolonged periods of sub-zero temperatures are rare.

Average annual precipitation is high, at 1281mm, and occurs mostly in the late fall and early winter. Rainfall accounts for 94% of the total. Snowfall is limited, an average of 85 cm per year generally falling between November and April. This light snowfall, combined with mild temperatures and frequent rains, results in ephemeral snow cover at sea level. For most coastal stations, the average annual number of days with snow cover exceeding

Figure 1. Map of Queen Charlotte Islands, British Columbia, Canada.


133°
132°
131°
54°
53°
52°
GRAHAM I.
Lawnhill
Sandspit
Louise I.
Lyell I.
MORESBY I.
Burnaby I.
0 25 50
km
Kunghit I.
Cape St. James


BRITISH
COLUMBIA

2.5 cm is <20 (Calder and Taylor 1968). Strong winds are prevalent throughout the QCI. Average monthly wind speeds for Sandspit range from 14-21 km/hr, but winds along the west coast are stronger and more frequent than those along the east coast. For example, average wind speeds for Cape St. James (Fig. 1) are typically twice the speed of those at Sandspit. Periods of calm at Sandspit occur 10-20% of the time, whereas periods of calm at Cape St. James occur <1% of the time (Calder and Taylor 1968).

Vegetation

The Queen Charlottes are largely covered by coniferous forest, with three of British Columbia's fourteen biogeoclimatic zones present (Banner et al. 1989). The Coastal Western Hemlock zone predominates, with pockets of Mountain Hemlock and Alpine Tundra at higher elevations. Banner et al. (1989) describe these biogeoclimatic zones and their dominant plant associations.

In the Queen Charlotte Mountains and Skidegate Plateau, forests of western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), western red-cedar (*Thuja plicata*) and yellow cedar (*Chamaecyparis nootkatensis*) occur, with dominance varying depending upon local topography, slope and soil conditions (Banner et al. 1989). In areas with limited relief, such as the Queen Charlotte Lowland, poor drainage has resulted in sparse timber cover and the development of extensive bogs and swamps. Throughout the QCI, the native understory vegetation has been substantially altered due to intensive browsing by introduced black-tailed deer (*Odocoileus hemionus*) (Pojar and Banner 1984).

Intertidal Zone

Shorelines of the QCI are characteristic of a recently glaciated coastline. Steep slopes and resistant underlying rock have allowed only limited beach development. Thus, much of the shoreline, with the exception of the extensive sand beaches on the northeastern tip of Graham Island, consists of bedrock interspersed with cobble and boulder pocket beaches (Holland 1976). Tidal amplitude ranges from 3 to 5 m, with a mixed, predominantly semi-diurnal tidal pattern of two high and two low tides of unequal height (Thomson 1989). Intertidal flora and fauna are similar to that described for southern British Columbia and the U.S. Pacific Northwest (Kozloff 1983).

Mammals

The QCI have a depauperate mammalian fauna. Excluding four species of bats, the only indigenous land mammals are black bear (*Ursus americanus carlottae*), river otter (*Lutra* *canadensis pericylzomae*), pine marten (*Martes americana nesophila*), Haida ermine (*Mustela erminea haidarum*), two races of the dusky shrew (*Sorex monticolus*), and two undefined taxa of the deer mouse (*Peromyscus sp.*)(Cowan 1989). Sea otter (*Enhydra lutra*) were historically abundant, but were extirpated through the fur trade (Foster 1989). The region once contained Dawson caribou (*Rangifer tarandus dawsoni*), which became extinct in 1908 (Foster 1984).

Within the past century, at least nine mammals have been introduced to the QCI, but little information has been gathered regarding their effect on the native biota. Persisting introduced mammals are the black-tailed deer, elk (*Cervus elaphus*), red squirrel (*Tamiasciurus hudsonicus*), beaver (*Castor canadensis*), muskrat, raccoon, black or ship rat (*Rattus rattus rattus* (L.) and *R. r. alexandrinus* (Geoffroy-Saint-Hilaire)), Norway rat (*R. norvegicus*), and house mouse (*Mus musculus*)(Cowan 1989, Foster 1989). The region contains no important predators of the raccoon, within either the indigenous or introduced fauna.

Seabirds

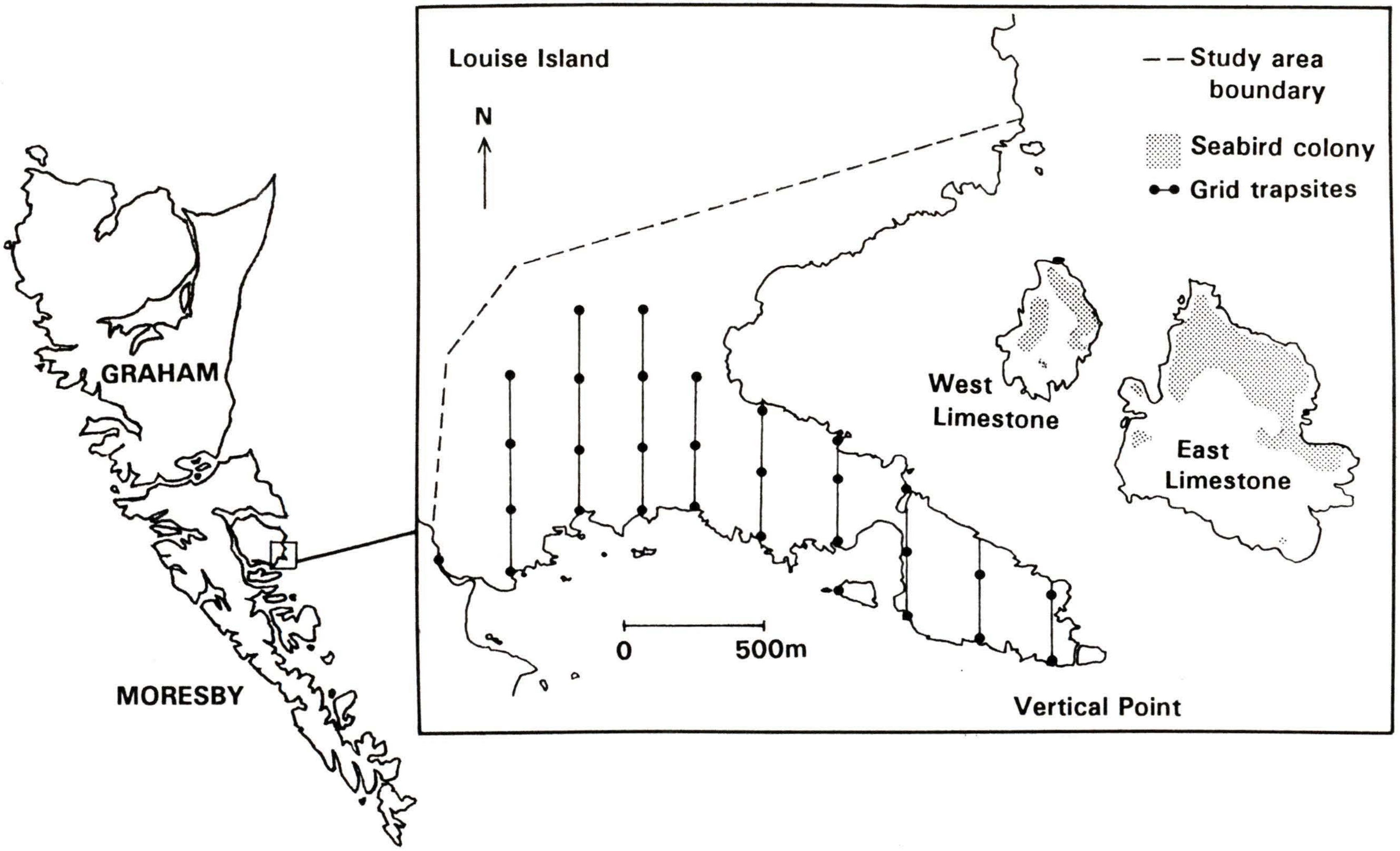
Burrow-nesting seabirds breed at 64 sites in the QCI, with populations ranging from 4 to 316,000 birds (Appendices A and B) (Rodway et al. 1988, 1990, and unpubl. data). Most birds (84%) are concentrated at 14 major colonies, each of which contains >25,000 birds. Colony islands range in size from <1 to 13,000ha, and require over-water crossings of up to 3750 m from Graham or Moresby Island. Most burrow-nesters breed on islands or island clusters >50 ha in size (78%) and <1 km offshore (76%).

The timing and duration of seabird breeding activity varies depending upon the species (Campbell et al. 1990). Ancient Murrelets begin to arrive on the colonies in March. Because of the precocial development of the chicks, most have departed by mid-June. Other burrow-nesting species on the QCI arrive on the colonies between March and May, and remain present until August, or in the case of Storm-Petrels, as late as September or October.

Vertical Point and the Limestone Islands

The principal study area included Vertical Point, on the southeast side of Louise Island, and the adjacent East and West Limestone Islands (Fig. 2). Vertical Point (VP) was the study site for the investigation of raccoon ecology in the absence of seabirds. East Limestone Island (EL) was the main study area for the study of raccoon ecology in the

Figure 2. Map of study area - Vertical Point, Louise Island and the Limestone Islands.


Louise Island
N
--- Study area boundary
▨ Seabird colony
●-● Grid trapsites
GRAHAM
MORESBY
West Limestone
East Limestone
0 500m
Vertical Point

presence of seabirds.

The study area was selected on the basis of biological, logistic and political considerations. The unresolved issue of the management of South Moresby National Park Reserve precluded research throughout most of the southern half of the archipelago. The west coast was considered too difficult and hazardous an area in which to work, because of its wind and wave exposure. Among the few remaining sites, safe moorage and the ability to consistently maintain radio-contact were of fundamental importance, as were the presence of raccoons and seabirds.

VP and the Limestone Islands met these criteria; raccoons were known to be present at VP, and EL and adjacent West Limestone (WL) contained Ancient Murrelet colonies. In addition, raccoons were suspected by seabird researchers to have visited these islands previously (Summers and Rodway 1988). VP and the Limestone Islands therefore offered the possibility to study raccoons, and to document their activity on an active seabird colony.

Vertical Point

Vertical Point is an area of rugged topography, underlain by limestone and basaltic bedrock. The extreme tip of the point is bounded by 15-30 m limestone cliffs, from which the area derives its name. Less conspicuous, slightly forested cliffs also extend along the southern shore of the study area. The maximum elevation within the study area is 50 m.

Study area boundaries were delineated on the basis of local features and practical considerations. A stream formed the western boundary of the study area on VP, and the northern boundary was determined according to the maximum area which trapping effort could encompass (Fig 2.). The grid trapline extended 750 m inland, and steep slopes limited access to approximately 250 m beyond this. The northeastern extent of the study area was determined largely on the basis of the movements of collared animals, and coincided with steep limestone cliffs directly north of West Limestone Island. Shoreline formed the southern and eastern boundaries. These boundaries encompass an area of approximately 190 ha.

Vegetation was predominantly open coniferous forest, with principal species varying according to local site conditions. Sitka spruce occurred on rocky headlands exposed to salt spray, and on beach deposits. Red alder (*Alnus rubra*) occurred in poorly drained and disturbed sites, whereas upland areas were dominated by western hemlock, Sitka spruce and some western red-cedar. Limited logging approximately fifty years ago left large stumps throughout the area which, along with snags and fallen trees, provide numerous cavities. Moss covered the forest floor, but understory vegetation was sparse.

The shoreline of VP was typical of the east coast of Moresby Island and adjacent islands. It was characterized by pocket beaches backed by loglines, and flanked by bedrock outcrops. Several habitats were identified in the study area on the basis of beach material, including one mudflat, two sand beaches, numerous cobble-boulder beaches, and bare limestone and basalt bedrock.

Visible differences existed in the intertidal flora and fauna of each of these habitats. The mudflat and sand beaches contained little visible intertidal fauna, but a rolled kelpline containing abundant amphipods and other invertebrates was often present. Limestone bedrock occurred in exposed areas, and also supported a limited intertidal flora and fauna. The richest and most extensive intertidal habitat occurred within basalt bedrock and cobble-boulder beaches. Such rocky shorelines were inhabited by limpets, isopods and encrusting algae in the spray zone. Littorinid snails were abundant in crevices and tidepools of the upper high tide zone, or barnacle zone, and within the band of rockweeds (*Fucus* sp.) of the middle high tide zone. Shorecrabs (*Hemigrapsus* sp.), hermit crabs, whelks, amphipods, and tidepool fish all extended from the high tide zone into the middle tide zone, where mussels (*Mytilus* sp.), anemones (*Anthopleura* sp.) and, in exposed locations, gooseneck barnacles (*Pollicipes* sp.) also occurred. Among the common algae of the middle tide zone were *Ulva* sp., *Leathesia* sp., *Halosaccion* sp., *Gigartina* sp.. Common organisms in the low tide zone included purple sea urchin (*Strongylocentrotus purpuratus*), kelp crabs (*Pugettia* sp.), abalone (*Haliotis* sp.), and several species of large brown algae (*Iridaea* sp., *Egregia* sp., *Laminaria* sp., *Alaria* sp., *Nereocystis* sp. and *Macrocystis* sp.).

The Limestone Islands

East and West Limestone Islands lie 375 and 300 m offshore of Louise Island, respectively. EL has an area of 48 ha, WL 11 ha. Both the physiography and the vegetation of the islands are similar to that of VP. The shoreline differs, however, containing no mud flats, no sand beaches and less cobble-boulder habitat. Proportionately more of the shoreline is made up of bare limestone bedrock, particularly on the exposed northeastern side of the islands.

Both islands contain colonies of Ancient Murrelet (Fig. 2). When surveyed in 1983, WL had a colony area of 4.4 ha, and an estimated nesting population of 106 +/- 50 pairs (+/- SE) (Rodway et al. 1988). Burrow occupancy was 20%, substantially lower than the QCI's median occupancy rate of 63% (Rodway et al. 1988). EL housed a colony of 1449 +/- 305 breeding pairs of Ancient Murrelets within an area of 14.9 ha, located primarily on the NE side of the island. Burrow occupancy was 61%. When re-surveyed in 1989, the population of Ancient Murrelets on EL was estimated at 1215 +/- 250 pairs (Gaston et al. 1989). Although this estimate falls within the 95% confidence limits of the 1983 one, burrow occupancy had decreased significantly, to 40% ($X^2 = 5.51$, $P<0.02$)(Gaston et al. 1989).

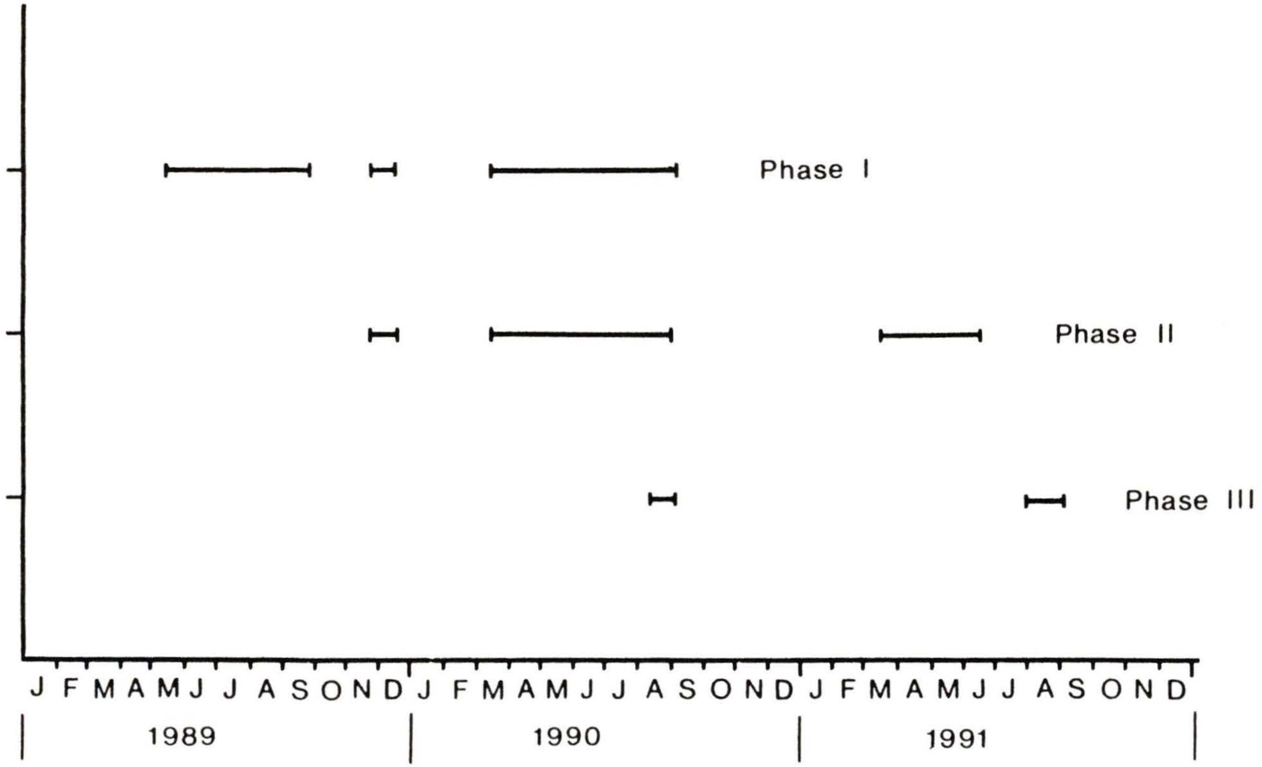
STUDY SEASONS

Field work took place between May 1989 and August 1991. Four field seasons were completed, totalling 1.5 years of field work (Fig. 3). These field seasons addressed the following phases in the research:

Phase I:	the study of raccoons in the absence of seabirds (VP),
Phase II:	the study of raccoons in the presence of seabirds (EL), and
Phase III:	the description of raccoon distribution in the QCI.

Phase I was the focus of field work in the summers of 1989 and 1990, and briefly during the intervening winter. Phase II began in the winter of 1989, was carried out concurrently with Phase I the following summer, and was completed in the summer of 1991. Phase III was carried out within 2-3 week periods in August of 1990 and 1991.

Figure 3. Time and duration of data collection for Phases I-III of the study.


Phase I
Phase II
Phase III
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1989
1990
1991

CHAPTER 1. DIET OF COASTAL RACCOONS OF THE QCI IN THE PRESENCE AND ABSENCE OF BURROW-NESTING SEABIRDS

INTRODUCTION

The nature and availability of alternative prey is a major factor influencing the severity of alien predation on breeding seabirds (Moors and Atkinson 1984). The presence of alternative foods is critical to the survival of the predator when seabirds are absent, and the predator's preference for those alternative foods influences the extent to which the predator preys on breeding seabirds when present. This chapter documents the diet of raccoons both in the presence and absence of seabirds, to determine what raccoons eat when seabirds are absent, and whether they switch to seabirds when available.

To date, no studies have investigated the diet of raccoons in the QCI. However, the general pattern of more than 17 studies from the United States is that plant matter dominates the diet in forested or cultivated inland regions (Giles 1940, Wood 1954, Johnson 1970, Cowan 1973, Tabatabai and Kennedy 1988), whereas animal matter, particularly crustaceans, is more heavily used in marsh and coastal habitats (Tyson 1950, Dorney 1954, Fleming et al. 1978, Harman and Stains 1979). These results suggest that coastal raccoons in the QCI will feed on crustaceans, and the region's extensive intertidal zone will provide a staple food source throughout much of the archipelago, including offshore islands.

Raccoons often shift their diet in response to changes in the availability of a food source (Giles 1940, Hamilton 1940 and 1951, Yeager and Rennels 1943, Baker et al. 1945, Yeager and Elder 1945, Schoonover and Marshall 1951, Greenwood 1981). Johnson (1970) cited the importance of learned behaviour in prompting the exploitation of a newly discovered food source, and consistent with this, Urban (1970) suggested that waterfowl nest destruction by raccoons varies individually, depending upon efficiency at finding nests and preference for eggs. The opportunistic foraging behaviour of raccoons, and their documented role as nest predators, suggest that at least some raccoons will shift their diet to exploit seabirds as a food source when available.

METHODS

Field Methods

Diet was studied by analyzing systematically collected, known-age scats. Raccoon scats were easily distinguished from those of river otter, the only other mammal of similar size present in the area. Although both species defecate in "latrines" close to shore, their scats and latrines differ in both appearance and location. Otter latrines were usually associated with heavily trampled dens and runways. Scats contained primarily the bones and scales of large fish inaccessible to raccoons under most conditions: they were black and mucousy when fresh, and bleached to greenish white over time. Large areas of moss tended to be discolored at otter latrines, by compounds in the urine and/or feces.

Raccoon latrines were located mostly at the base of trees, or on elevated features such as knolls, stumps and fallen logs. They were seldom associated with otter latrines. Scats were large and similar in shape to those of dogs, contained primarily intertidal food items, and bleached to a pinkish white. Ground vegetation was not discolored at raccoon latrines.

Observations made while chaining trapline transects on VP indicated that most raccoon latrines were concentrated within 10 m of the shoreline. In 6,400 m of chaining through the forest, only 18 latrines were found. Most contained only 1-2 very old scats, similar in composition to those along the shoreline. By contrast, the same number of latrines could be found within a 200-300 m length of shoreline, and many of these latrines contained dozens of accumulated scats.

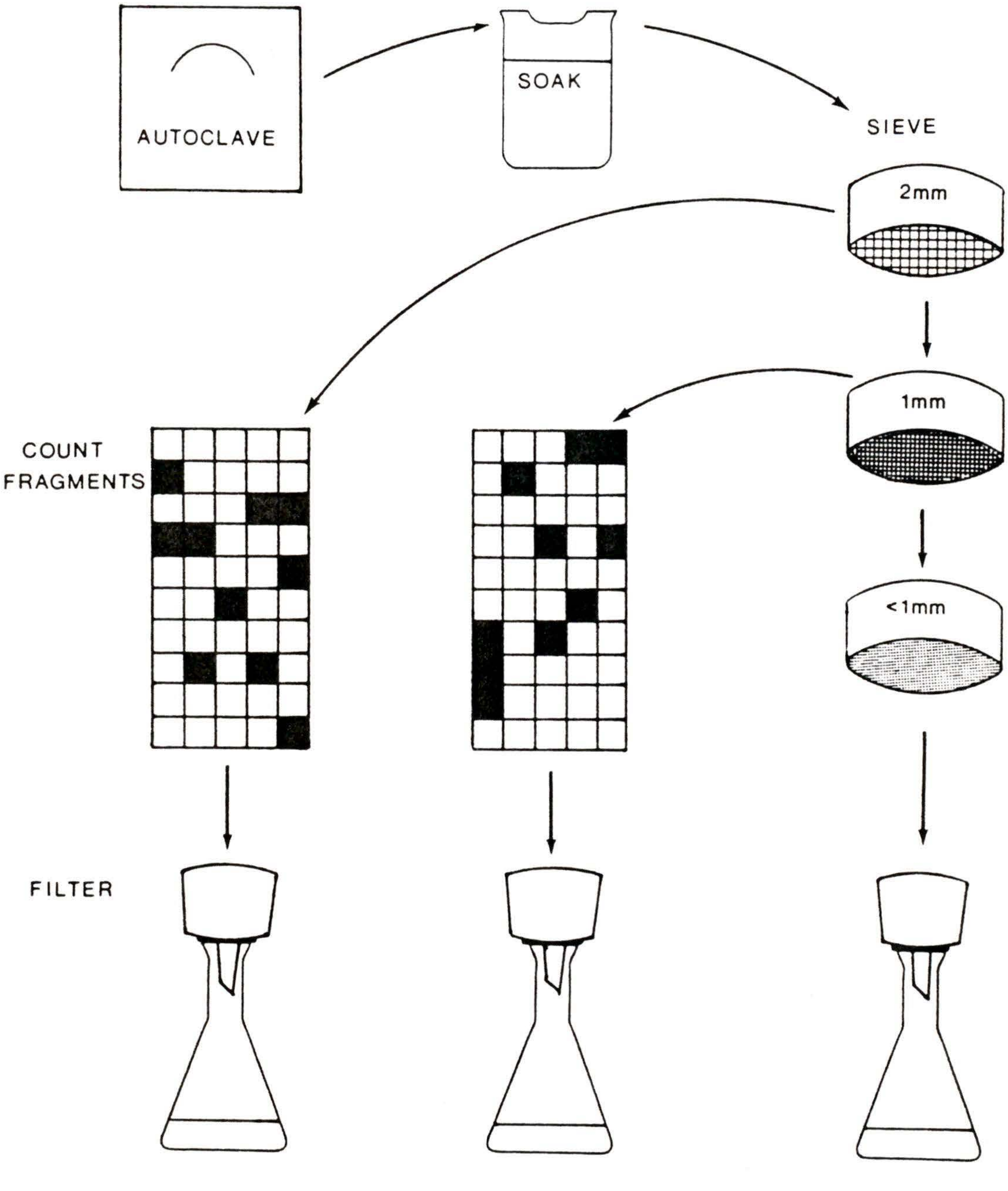
As a result of these observations, 300-m latrine circuits were established along the shoreline of VP and EL for the collection of scats. Along these circuits, extending 10 m inland from the vegetation edge, all latrines were flagged and cleared biweekly to obtain known-age samples. Scats were placed in paper bags, labelled as to date and location, and frozen as soon as possible, from 1-14 days later.

Laboratory Methods

Conventional scat analyses often rely on percentage volume and percentage frequency measures to characterize diet (Korschgen 1980). The measurement of percentage volume was impracticable in my study because the particles were too numerous (several thousand) and small (<2 mm). Consequently, scats were analysed with a "fragment count" method, illustrated in Figure 4 and outlined below.

For practical reasons, scats collected at Vertical Point were first subsampled for analysis. Preliminary observations indicated that five scats, randomly selected from each of the

Figure 4. Schematic illustration of method used to quantify contents of raccoon scats.


AUTOCLAVE
SOAK
SIEVE
2mm
1mm
<1mm
COUNT FRAGMENTS
FILTER

eleven sampling periods, was an adequate sample. All scats collected on East Limestone Island were analyzed (n=12).

Sampled scats were first autoclaved for twenty minutes in a standard wet cycle to kill eggs of *Baylisascaris procyonis,* an ascarid parasite fatal to most vertebrates, including humans, if ingested (Kazacos and Boyce 1989). *Baylisascaris procyonis* is prevalent in most raccoon populations, and was present in 2 of 12 scats from VP analyzed by the Abbotsford Animal Health Centre. Several scats were visually inspected and described before and after autoclaving to confirm that contents were not destroyed nor substantially altered by the process.

Each scat was then soaked in water for 2 to 3 days to separate particles. To facilitate counting and identifying fragments, scats were then sieved into three size classes: >2 mm, 1-2 mm, and <1 mm. The smallest size class was immediately filtered and air-dried, its volume measured, and contents stored without analysis. The two larger size classes were analyzed separately. Sieve contents were washed into a plexiglass tray with a grid of fifty, 4-cm x 4-cm squares drawn on the bottom. The number of particles of each food type was counted in ten randomly selected squares. Contents of each tray were then filtered and air-dried for storage. Using this method approximately 20% of each scat was identified.

Data Analysis

Fragment counts for the >2 mm and 1-2 mm fragments were combined in presenting the results, and formed the basis for comparisons of scat content among time periods and between locations. Rather than obtaining a percentage volume measurement for the items within each scat, a percentage fragment count was obtained. As with percentage volume measurements, however, the fragment count allowed a comparison of the proportion of various food remains present within each scat, and permitted determination of their percentage frequency.

RESULTS

The Vertical Point circuit was initially cleared of scats on December 7 1989, and the first collection was made on March 23 1990. This first collection contained scats deposited over the preceding 3.5 months. Ten subsequent collections were made approximately biweekly until August 16 1990. A total of 295 scats was collected (Table 2).

Table 2. Number of scats collected per sampling period at Vertical Point, March 23 to August 16, 1990.

SAMPLING PERIOD	DATE	DAYS ELAPSED SINCE LAST COLLECTION	NUMBER PRESENT	NUMBER COLLECTED
1	March 23	106	119	106
2	April 5	13	25	25
3	April 20	15	29	29
4	May 5	15	20	20
5	May 16	11	11	11
6	May 31	15	19	19
7	June 18	18	19	19
8	July 4	16	12	7
9	July 19	15	20	20
10	August 2	14	13	13
11	August 16	14	26	26
TOTAL			313	295

Table 3. Number of scats collected per sampling period on East Limestone Island, April 6 to June 7, 1991.

SAMPLING PERIOD	DATE	DAYS ELAPSED SINCE LAST COLLECTION	NUMBER PRESENT	NUMBER COLLECTED
1	April 6	9	2	2
2	April 25	19	8	8
3	May 8	13	2	2
4	May 22	14	0	0
5	June 7	16	0	0
TOTAL			12	12

The East Limestone circuit was established March 26-28 1991. Five collections were made approximately biweekly from April 6 to June 7 1991, within the main period of seabird breeding activity. A total of twelve scats were collected (Table 3).

The number of scats collected at the two different sites differed markedly. On VP, collections between April 5 and May 31 1990 produced 104 scats, whereas on EL, collections during a similar time period in 1991 produced only 12. These differences reflected differences in numbers of raccoons on the two study sites (Chapters 2 and 3).

Of the 55 scats sampled from VP, four were incompletely analyzed and were removed from the results. In two of the four cases, scats consisted entirely of fine particulate matter that lacked identifiable features. In the remaining two scats, clumping of food residue prevented standard processing so that the results were not comparable with other scats that were analyzed. Scats removed from analysis came from sampling periods 2, 3, 4 and 11, reducing the sample size for each of these periods from 5 to 4.

Vertical Point

Scat Composition

At Vertical Point, scats consisted almost entirely of intertidal foods. Such remains occurred in all scats and comprised 90% of the total fragment count (Table 4). The most common remains were those of shore crab (primarily *Hemigrapsus nudus*) and amphipod, which occurred in 85 and 76% of all scats, respectively, and comprised 89% of all intertidal invertebrate fragments. Other identifiable intertidal invertebrates ranged from 2 to 39% frequency, but collectively contributed only 3% of the total fragment count. Unidentifiable invertebrate matter was present in most scats (84%) but constituted only a minor portion of fragments (7%).

Both fish and insects comprised little of the total percent fragment count, but were eaten relatively frequently. Fish represented <1% of the fragment count, but were present in 23% of scats analyzed. Fish remains were limited to vertebrae approximately 3mm in size, including projections. Although classification was not routinely taken to a more detailed level, a small sample of these vertebrae were identified as intertidal sculpins by B. Wigen of the Anthropology Department, University of Victoria. Insect remains comprised only 2% of the fragment count, but occurred in 41% of scats.

Table 4. Percentage frequency of occurrence and percentage fragment count of food items present in scats collected at Vertical Point, Louise Island, March 23 - August 16 1990.

FOOD ITEM	FREQUENCY (n=51) (%)	FRAGMENT COUNT (%)
Intertidal invertebrate	100	90
Crab	*85*	*34*
Amphipod	*76*	*46*
Isopod	*39*	*2*
Limpet	*24*	*<1*
Snail	*14*	*<1*
Mussel	*2*	*<1*
Sea Urchin	*4*	*<1*
Pelagic Gooseneck Barnacle	*8*	*<1*
Unidentified	*84*	*7*
Fish	23	<1
Insect	41	2
Bird	0	0
Mammal	6	<1
Vegetation	82	3
Unknown/unidentifiable	76	4

Most common were carabid beetle remains, which accounted for 77% of the total insect material. Fly larvae, either consumed by the raccoon or developing on the scat following deposition, comprised 15% of insect material. Other adult insects, including wasps and unidentified insect fragments, formed the remainder of this category.

Bird remains were absent in VP scats. Mammal remains were uncommon, present in only 3 of 51 scats and comprising <1% of the total fragment count. Such remains included only a few small pieces of bone, and tissue with hair affixed.

Vegetation occurred in 82% of the scats analyzed, but comprised only 3% of the fragments counted. Half of the vegetation fragments were unidentified. Among the remainder, conifer fragments (e.g. hemlock, cedar) predominated, followed by terrestrial and aquatic grasses. Much of the vegetation, particularly the conifer fragments, may have been collected or ingested incidentally.

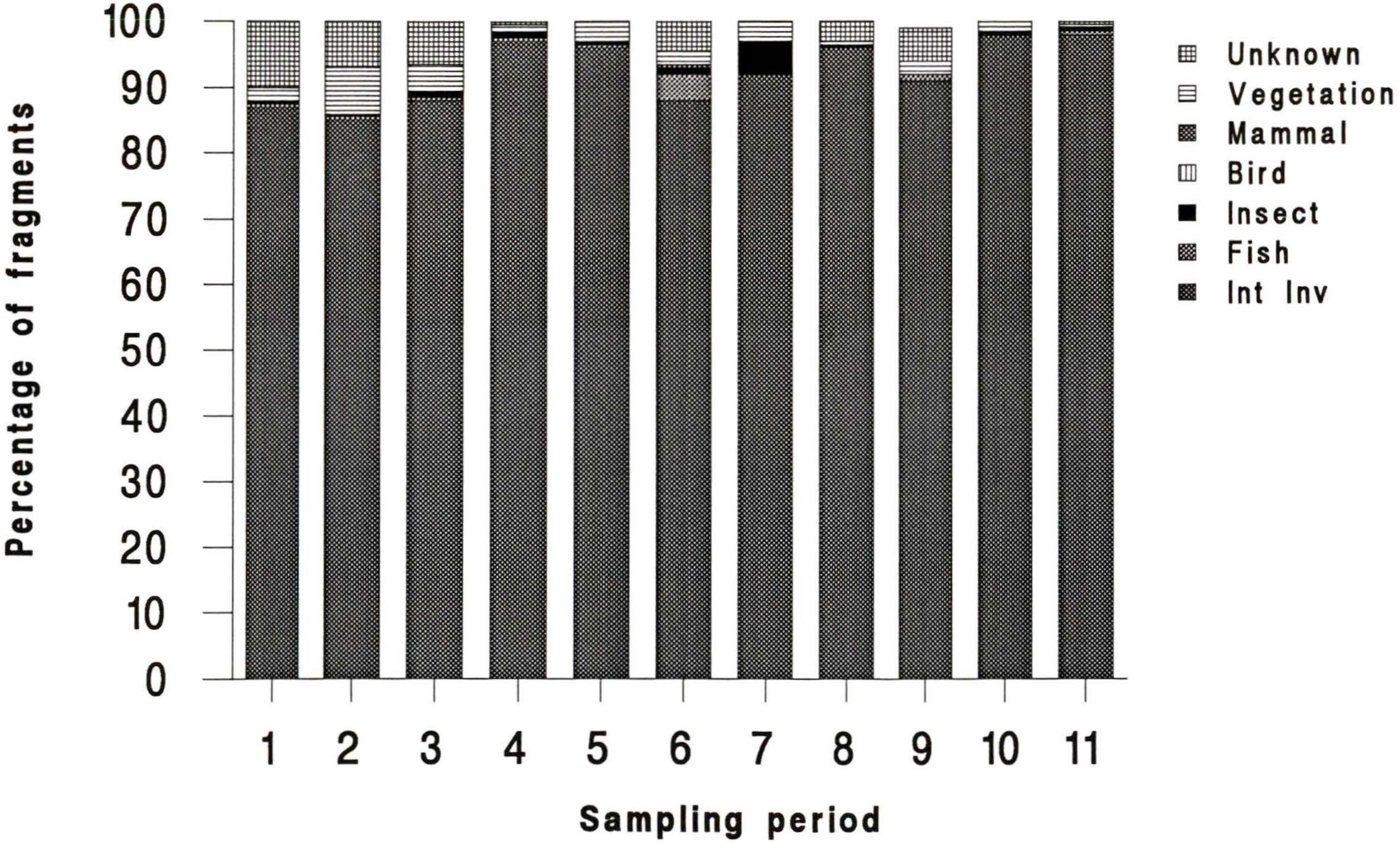
Unknown fragments were those which could not be identified even as plant or animal. Given the size of the fragments being analyzed, it is not surprising that unknown fragments were present in a large number of scats (76%). However, they comprised only 4% of the total fragment count (>1 mm). These fragments were likely non-diagnostic pieces of food items already identified in the scat, as opposed to unique and unrepresented food items.

Dominance of a particular food item within one or a few scats may indicate the presence of a food item available only periodically, but consumed heavily when present. However, the relative quantity of each category of food item present within individual scats indicates the consistency with which intertidal foods were eaten. Intertidal invertebrates comprised at least 40% of the fragment count of all individual scats: in 40 of 51 scats, they comprised 91-100% of the fragments present. By contrast, food items in other categories comprised a maximum of 50%, and most often 0-10%, of the fragments in any given scat.

Constancy of Scat Composition

The proportion of intertidal invertebrates in raccoon scats from VP varied little during the five month period of study, contributing approximately 90% of all fragments within each sampling period (Fig. 5). Other categories of food items contributed varying but minor proportions of the total; it is likely that a larger sample size is needed to identify significant seasonal variation in these categories.

Figure 5. Temporal variation in the relative proportion of seven categories of food item, in scats collected at Vertical Point, March 23 August 16 1990. Proportions determined by fragment count (Int Inv = Intertidal invertebrates).


100
90
80
70
60
50
40
30
20
10
0
Percentage of fragments
1
2
3
4
5
6
7
8
9
10
11
Sampling period
Unknown
Vegetation
Mammal
Bird
Insect
Fish
Int Inv

East Limestone Island

Scat Composition

Scats collected on EL during the seabird breeding season differed from those from VP. The principal difference was the occurrence of seabird remains, and the reduced proportion of intertidal invertebrate matter (Table 5). Seabird remains were present in all 12 scats, and comprised 43% of the total fragment count. Remains were mainly the bones and feathers of grown birds: almost no eggshell was found. Bone fragments were examined by B. Wigen of the Anthropology Department. Of the 12 scats collected, two contained bone fragments identified as either Ancient Murrelet or Cassin's Auklet, three contained Ancient Murrelet, and at least four and possibly six contained Cassin's Auklet. One scat did not contain sufficient diagnostic bone fragments to determine family or species.

Head and neck fragments (i.e. beak, quadrate, atlas, cervical vertebrae and mandible) were present in 10 of 12 scats, consistent with field observations of decapitated adult birds. Portions of sternum were present in six of the scats, furculum and pelvis in four, and feet in two. Counts of quadrates and atlases indicated that two scats contained the remains of at least two birds, and one scat the remains of at least four.

Scats from EL contained a lower proportion of intertidal invertebrates than those from VP. Intertidal invertebrates were present in only 7 of 12 (57%) EL scats and constituted only 20% of the total fragment count, compared with 100% and 92%, respectively. Fish were not well represented in either frequency (1 of 12 scats) or fragment count (0.2%). Insect remains, although found in as many scats as intertidal invertebrates, constituted only 2% of the fragment count. Mammal remains were not present in any of the scats.

Vegetation was present in all scats but formed <7% of the fragments. Unknown food remains, also present in all scats, were more abundant in EL samples (28%) than in VP scats (4%). Much of the unknown category consisted of membranous fragments which probably represented seabird tissues, but were not diagnostic. Because of the small number of scats collected on EL, constancy of scat composition over the period of study was not evaluated.

Table 5. Percentage frequency and percentage fragment count of seven categories of food items for 12 scats collected at East Limestone Island, April 6 - June 7 1991.

FOOD ITEM	FREQUENCY (n=12) (%)	FRAGMENT COUNT (%)
Intertidal invertebrates	57	20
Fish	8	<1
Insect	57	2
Bird	100	43
Mammal	0	0
Vegetation	100	7
Unknown/unidentifiable	100	28

DISCUSSION

Evaluation of the methods

Scat analysis is one of the commonest methods used to infer diet. However, the interpretation of results based on scat analysis is profoundly influenced by the methods of collection and analysis used in the field and laboratory, respectively. Methods of collection determine how well the sample reflects temporal, spatial and individual differences in the diet of the population studied, and methods of laboratory analysis determine the reliability of the quantitative description of scat composition.

In this study, scats were collected biweekly to ensure representation throughout the period of study, and to minimize bias favouring persistent scats. Collections were made along the shoreline where most scats were concentrated. For the reason outlined previously (Methods) this is not thought to have significantly biased results against more dispersed, inland food items. Because collections were made from a series of adjacent latrines, however, the question arises of whether such scats represent those of the local population, or were deposited by only one individual. Telemetry data indicate that the latrine circuits on both VP and EL fell within the home range of at least 2-3 collared raccoons, and an unknown number of uncollared raccoons (Chapter 2). Also, scats from the collection circuits did not differ noticeably from others along the shoreline, suggesting that the collected scats were representative of those produced by the local population.

Analysis of a 20% sub-sample of each scat, and the omission of the smallest size fraction were potential sources of error and bias in the description of scat composition. The low variability noted among quadrats suggests that a 20% sub-sample was adequate, and visual inspection of the smallest size fraction indicated that it contained primarily the dominant items of the scat. The methods used here could require modification, if the scats sampled are highly variable in content, or contain items which do not dissociate well (i.e. hair). In this study, however, the method permitted the comparison of scat content on the basis of a standardized description, not biased against less abundant or less identifiable items within the scat.

Perhaps the most important factor influencing the interpretation of results is the difference between foods eaten, and the fecal residue produced. The composition of food items, and the manner in which they are eaten, determine the quantity of identifiable food items in the scat (Greenwood 1979). Foods with substantial undigestible residue are over-represented in volumetric measures (or in this study, fragment counts) relative to soft-bodied or highly digestible items, and foods eaten often but in low quantities tend to be over-represented in measures of percentage frequency. To partially offset these biases, this and most other studies present results using both measures (Korschgen 1980); nonetheless, results provide only an approximation of the species' diet.

Comparison with previous studies

Several recurring themes emerge in the literature on raccoon diet. Most noteworthy is the diversity of food items taken, both within and between studies. Numerous studies report the consumption of several dozen kinds of food, and collectively diet studies reveal the use of hundreds of species within all major food categories: plant, invertebrate, amphibian, reptile, fish, bird and mammal.

In this study, raccoons in an area devoid of seabirds ate primarily intertidal foods, while raccoons on an active seabird colony fed primarily on seabirds. Their diet in both areas was composed almost entirely of animal matter, and showed little variation within the period of study. This relative lack of diversity in the diet, and the paucity of plant material, is in marked contrast to the diet described for raccoons from most inland habitats, but is consistent with results obtained in other coastal studies.

Tyson (1950) reported that raccoons in coastal Washington fed almost exclusively on intertidal invertebrates. As raccoons were shot while feeding, apparently on the beach, these results may be biased. Crustaceans were the major food item of raccoons in coastal marsh habitats of Louisiana, where plant matter comprised only 6% of the annual diet of raccoons inhabiting brackish marsh (Fleming et al. 1978), and in Georgia, where fiddler crabs dominated the diet 11 months of the year (Harman and Stains 1979).

Scats were not collected year-round on the QCI. Thus, I do not know whether use of intertidal invertebrates at VP varies seasonally. Both Fleming et al. (1978) and Harman and Stains (1979) found that plant matter formed an important part of the diet outside of summer. In coastal Louisiana, hogcane (*Spartina cynosuroides*) occurred in 27% of fall scats, and in coastal Georgia, cordgrass (*S. alterniflora* and *S. patens*) occurred in 47-62% of winter and early spring scats. Use of cordgrass was attributed in part to poor production of acorns the previous fall; thus, such plant foods may be significant to the overwinter survival of the raccoons (Harman and Stains 1979).

Although collection of scats throughout the year might have indicated greater seasonal use of plants in the QCI, this is unlikely for several reasons related to the availability of plants. The QCI is a sparsely populated wilderness area, and thus has no significant areas of grain production. No acorns or other types of mast are present. Also, the QCI lack several of the berry-producing species present on the adjacent mainland, such as *Prunus virginiana*, *Rhamnus purshiana*, and several species of *Ribes*, *Rubus* and *Vaccinium* (Calder and Taylor 1968). Perhaps most important, the native vegetation has been heavily browsed by black-tailed deer (Pojar and Banner 1984), reducing the abundance of those native berry-producing species present on the archipelago, such as salal (*Gaultheria shallon)* and huckleberries (*Vaccinium* sp.). A study of raccoon diet in inland areas of the QCI, or areas not affected by deer, would be instructive.

Insects were second to intertidal invertebrates on both VP and EL in frequency of occurrence. Insects are not well represented in percentage volume figures, but in many studies they are seasonally important, occurring in over half of collected scats (Giles 1940, Yeager and Rennels 1943, Yeager and Elder 1945, Cabalka et al. 1953, Wood 1954, Tabatabai and Kennedy 1988). The most frequently reported insect food items are coleopterans, orthopterans and hymenopterans.

At least 57 species of coleopterans occur on the QCI, 2 of which are endemic species inhabiting cobble-boulder beaches (Kavanaugh 1989). No identification of beetle remains was attempted, but it would be interesting to investigate the possible effect of raccoon predation on these endemics, as they are locally concentrated high on the beach, near freshwater seepages and creeks (D. Kavanaugh, pers. comm. 1993). Hymenopterans were present in few scats, but excavated wasp nests were found on the forest floor on 5 occasions. Orthopterans were not detected in scats, nor noted in the study area.

Fish were present in 23% and 8% of scats from VP and EL respectively, values slightly lower than those reported in other studies of coastal or marsh raccoons. The highest recorded measure of fish in the diet comes from Tyson (1950), who found fish in 59% of the stomachs of raccoons from coastal Washington. However, the sampling method employed in Tyson's study may have resulted in an over-representation of intertidal foods. Fleming et al. (1978) found fish in 36% and 42% of spring and fall scats, respectively, in brackish marsh habitat of coastal Louisiana. Dorney (1954) reported fish in approximately 20% of spring-fall scats from marsh habitat in Wisconsin.

These values for fish are greater than those reported for most inland regions. Studies from Michigan (Stuewer 1943), Illinois (Yeager and Rennels 1943, Yeager and Elder 1945) and Tennessee (Tabatabai 1988), report a maximum seasonal occurrence of 10-15%, with the values for Illinois attributed to scavenging. All remaining studies have shown little consumption of fish (Baker et al. 1945, Schoonover and Marshall 1951, Tester 1953, Wood 1954, Kinard 1964, Johnson 1970), or none at all (Hamilton 1940 & 1951, Cowan 1973, Greenwood 1981). No reptiles or amphibians were present in the diet of raccoons in this study, which is not surprising given the paucity of such species present on the archipelago (Green and Campbell 1984, Gregory and Campbell 1984), and the limited proportion of the diet they typically comprise (Dorney 1954, Hamilton 1940, Johnson 1970).

Mammals and birds are not usually preyed on heavily, but "where abundant and easily obtained, they may be heavily utilized" (Johnson 1970). Wilson (1953) and Errington (1967) have both described heavy predation on muskrat kits. Llewellyn and Webster (1960) and Urban (1970) have also reported heavy predation on nesting waterfowl. No snap-trapping was conducted within the study area; thus, no site-specific information is available on small mammals. Ermine (*Mustela erminea haidarum*), dusky shrews and deer mice are the only naturally occurring small mammals on the archipelago, but house mice, rats and red squirrels have now been introduced (Cowan 1989). Introduced beaver and muskrat are present in parts of the QCI (Cowan 1989), but were not found within the study area. The limited use of mammalian prey at VP and its absence in EL scats is consistent with the observations of most researchers (Johnson 1970).

Although no bird remains of any sort were present in scats from VP, seabirds dominated in both percentage frequency and percentage fragment count in samples collected on EL. Furthermore, their presence in the first scats collected in early April indicates that raccoons were preying on breeding seabirds within 1-2 weeks of the seabird's arrival on the colony. Yeager and Elder (1945) reported similarly heavy use of seasonally abundant birds in a comparison of raccoon diet prior and subsequent to the hunting season on an Illinois goose refuge. As the season progressed and crippled birds became increasingly abundant, the percentage frequency of bird remains in scats increased from 21% to 88%, and the percentage volume of bird remains increased from 3% to 65%. Thus, whereas non-colonial birds do not often comprise a major component of raccoon diet, local concentrations of birds can be heavily exploited.

Influence of raccoon diet on seabird vulnerability

The severity of alien predation on seabirds is influenced by the relative availability of seabirds and alternative prey in space and time, and the predator's foraging preferences (Moors and Atkinson 1984). Where alternative foods are inadequate or periodically lacking, introduced predators may be unable to persist on a colony island or may be maintained at levels too low to cause substantial losses to a colony. For example, Kadlec (1971) released 2-4 raccoons per year on very small colony islands (1-2ha) off the coast of Massachusetts, to explore their effectiveness in controlling Herring Gull (*Larus argentatus*) populations. In four years of study, 23 of 37 released raccoons disappeared before the seabird breeding season ended. Several raccoons were recaptured in poor condition in the early stages of the study, indicating that supplemental feeding was required to maintain the raccoon population. Similarly, Stonehouse (1962) believed that "conditions during the recurring lean months" on Ascension Island maintained the feral cat (*Felis catus*) population at a level low enough to enable breeding terns to persist. On the QCI, raccoons feed primarily on intertidal invertebrates in the absence of breeding seabirds. This food source is widespread, and likely readily available year-round, so that for many colony islands the lack of alternative prey is not likely to be a significant factor limiting the raccoon's persistence.

In some cases, predation on seabirds is limited by the presence of preferred alternative foods. For example, Cooper (1977) found that feral cats on Dassen Island preyed on the young of introduced rabbits to the exclusion of most other foods, including breeding seabirds. Introduced rabbits also comprised a substantial portion of the diet of feral cats on Kerguelen (Pascal 1980), occurring in 35-72% of stomachs collected over a 3-year period. Without rabbits as a food supply, seabird losses would likely be significantly increased, at least in the short term. Although a shift in diet was not documented directly on EL, comparison of the results from EL and VP suggests that such a shift occurs. The rapid detection and consumption of seabirds indicates that they were sufficiently more abundant, accessible or palatable to be taken over the intertidal foods which otherwise form the mainstay of the diet.

Similar results were obtained by Norman (1971), who documented a marked difference in the diet of foxes (*Vulpes vulpes*) in the presence and absence of breeding shearwaters. When shearwaters were absent rabbits were the dominant prey item, comprising 67% of the volume of scats. When shearwaters were present, however, the volume of shearwater remains increased from 6% to 40%, and that of rabbits decreased to 37%. Norman (1971) concluded that "whilst there was not a marked cycle of food preferences, the foxes took advantage of the birds' presence."

The ability of raccoons to survive on a food resource as predictable and extensive as intertidal invertebrates facilitates their widespread distribution, and enables year-round colonization of at least some seabird colony islands. The presence of this extensive food source also suggests that raccoons could eliminate seabirds without being adversely affected by declining numbers of seabird prey. Thus, the availability of this alternative food resource, and the tendency of raccoons to prey on breeding seabirds when present, combine to represent the most damaging of scenarios concerning the foraging ecology of an introduced predator, and its potential impact on breeding seabirds.

CHAPTER 2. HOME RANGE, MOVEMENT AND ACTIVITY PATTERNS OF COASTAL RACCOONS OF THE QCI IN THE PRESENCE AND ABSENCE OF BURROW-NESTING SEABIRDS

INTRODUCTION

The severity of alien predation on breeding seabirds is influenced partly by the extent to which habitat-use patterns and vagility of introduced predators place them in contact with the seabirds (Moors and Atkinson 1984). For prolonged contact to occur, predators must be able to survive on colony islands, or reach them frequently. Contact between predator and prey is further influenced by the degree of their spatial and temporal overlap (Woodward 1972, Moller 1983). The purpose of this study was to determine how raccoons meet their basic requirements for food, shelter and space in the absence of breeding seabirds, and to identify any changes in the time or location of activity occurring in the presence of breeding seabirds.

Previous studies have indicated that raccoons are non-territorial (Stuewer 1943), and typically maintain small home ranges of 40-200 ha (Kaufmann 1982). Both of these characteristics are likely to be advantageous in establishing resident populations on small colony islands. The raccoon is also nocturnal, and typically has a home range associated with water, features which contribute to their probability of contact with burrow-nesting seabirds. Ancient Murrelets breed from the shoreline to 300-400 m inland (Vermeer and Lemon 1986), and are most active in the colony at night (Gaston 1992).

Where raccoons do come in contact with seabirds, a concentrated but ephemeral food supply, predation may or may not be manifested in a change in the time or location of activity. In a detailed study of raccoon movements in a waterfowl marsh, Urban (1970) found no evidence that raccoons shifted their home range or movements in response to the presence of breeding birds. Ivey (1948), however, presented limited evidence that coastal raccoons alter their time of activity to take advantage of intertidal foods, and Grinnell et al. (1937) reported regular movements of over 5 km by two raccoons to visit a plum orchard.

Using telemetry and direct observations, I studied raccoon home range, movement and activity patterns in an area devoid of breeding seabirds, to aid in evaluating their ability to survive on colony islands, and to determine the extent to which their patterns of movement and activity correspond to the time and location of seabird breeding activity. Results were compared with those obtained for raccoons on an active colony island to identify any differences in home range size or location, movement or activity patterns associated with the presence of breeding birds as a food source.

METHODS

Capture and Handling

Initially all trapping was done with single-door box live-traps (Havahart Model 1079), because animals could easily be handled in them. Attempts to recapture collared raccoons with box traps were largely unsuccessful, hence some trapping later in the study employed padded legholds (#1 1/2), with one spring removed. Such traps could be sprung on the bare hand without pain, yet held firmly. Trapsites were baited liberally with fresh fish when each trapping session started, checked daily, and re-baited every one to two days.

Traps were distributed in two ways: on a grid or along coastal traplines. For the first 1-2 sessions on Vertical Point, traps were distributed on a grid to allow comparison of capture statistics in different habitats. Nine transects were established, each spaced 250 m apart and running due north from the shoreline. Beginning at the vegetation edge, traps were placed on each transect at 250m intervals, resulting in 2-4 traps per transect. A single trap was placed at the mouth of the creek which delineated the western boundary of the study area (Fig. 2). During two weeks of trapping using the grid, success was extremely low. To hasten capture of study animals, therefore, most traps were shifted to the shoreline during trapping session 2.

Throughout the remainder of the study, a series of traplines in the shore zone were established, with the number, type and distribution of traps varying according to the goals of each session. Sessions 3-4 were aimed at capturing new animals on VP; thus, box traps were widely and relatively evenly distributed along the shoreline. Sessions 5-7 focussed on the recapture of collared animals on both VP and EL. Therefore, a combination of box and leghold traps was employed, and their locations were concentrated within the nightly foraging range of each animal. Sessions 8-9 were aimed at capturing the one collared raccoon known to be present on the Limestone Islands, as well as any other raccoons present. Trapping effort was thus confined to the colony islands, using a combination of box and leghold traps.

Animals captured in box traps were manouevred into a handling cone (Sanderson 1987), weighed, and anaesthetized with intramuscular injections of ketamine hydrochloride (12-15 mg/kg). This dosage was intermediate to those reported in the literature (Bigler and Hoff 1974, Gregg and Olson 1975), and represented a compromise between handling and recovery times. Animals captured in leghold traps were anaesthetized using a custom-made jab stick, with doses based on the average mass of previously trapped animals. Animals were considered anaesthetized when gentle movement of a stick on the gums produced no bite response. This occurred within 2 to 5 minutes after injection.

Each captured animal was fitted with a radio-collar (Lotek Model SMRC-2) that weighed approximately 115 g, or roughly 2.5% of the body mass. Each transmitter had a unique frequency whose pulse rate varied depending upon whether the animal was active, inactive or dead. Numbered eartags (National Band and Tag Co., Size 4) were also affixed, body measurements taken, and general body and tooth conditions noted (see Appendix C for data). Handling was completed within 10 to 28 minutes, by which time animals were beginning to move their head and limbs slowly. Recovering animals were placed in a large ventilated plastic bucket, and released when active, usually two hours after injection.

Home Range and Habitat Use

Data Collection

Animals were located day and night using telemetry and spotlighting. Telemetry was conducted using a portable receiver (Telonics Model TR-2 and Lotek Model SRX 400) equipped with headphones, and a collapsible three-element yagi antenna. All day-time telemetry was conducted on foot. Because of the irregular terrain and steep cliffs within the study area, collared animals were approached to <300 m to obtain accurate bearings. Often >3 bearings were needed to provide reliable location data.

Night tracking was initially conducted on foot. However, because raccoons were active on the beach at night, such tracking frequently disturbed and displaced study animals. To reduce this disturbance, spotlighting by boat was attempted during the 1989 winter session. Spotlight surveys were carried out by two people in an ocean kayak, equipped with a 750,000-candlepower spotlight attached to a car battery. Locating the animals by this method proved easier, faster and less disruptive than locating them on foot, and subsequently became the standard method for obtaining night locations. Rarely, when a study animal was inland and was not located while spotlighting, it was subsequently tracked on foot to ensure that night locations were not biased in favour of the shoreline.

Attempts were made to obtain at least 40 radio-locations per study animal, per field season. Ackerman et al. (1989) considered this to be the minimum acceptable sample size for determining home range size, using the minimum convex polygon (MCP) technique (Hayne 1949). The MCP is a home range estimator which encloses a set of locations such that no internal angle of the polygon exceeds 180° (Ackerman et al. 1989).

Because the duration of field seasons, the number of collared animals, and the number of field workers differed between years, the frequency of radio-locations varied. The four collared animals monitored in the 1989 field season were located approximately every 1-2 days. For seven of the collared animals monitored in the 1990 season, locations were obtained on average every 3-4 days. The two animals monitored on the seabird colony were found one to two times per day during the peak of seabird breeding activity. All sampling was distributed throughout the 24 hour daily cycle, to adequately represent activity and movements. Day and night were defined according to sunset and sunrise within the study area.

Data Analysis

In the field, telemetry bearings were drawn on a 1:5000 base map of the study area and the animal location determined by triangulation. Most decisions concerning the acceptability of fixes were made at this time. Bearings of questionable accuracy were rejected. Although there is some subjectivity in this method, evaluation of telemetry bearings is best based on familiarity with the local topography and its effect on signals, and recent knowledge of the strength and nature of each signal.

Bearings were later analyzed with "Locate II" (Nams 1990), a commercially available program designed to determine animal locations utilizing a maximum likelihood estimator. At this time a few fixes producing error ellipses >1ha were removed. Universal Transverse Mercator (UTM) coordinates determined using "Locate II" did not differ substantially from those determined in the field, and they ranged from 0-50 m apart (X= 13 +/- 13 m S.D., n=301). Field coordinates were chosen for use in subsequent analyses, because they incorporated the observer's knowledge of local terrain (i.e. they placed shoreline fixes on land rather than in water).

"Program Home Range" (Ackerman et al. 1989) was used to calculate 95% and 100% MCP home ranges. Harmonic mean analyses were not chosen because of inadequate sample size, and ellipse models were rejected because raccoon locations did not conform well to the underlying distribution assumed by the model. The MCP measure of home range was also the most comparable with those used in other studies of raccoon home range.

Home range outlines (95 and 100%) and location coordinates were imported into a geographic information system (PAMAP Systems, Victoria, B. C.) for analyses and map production. The 100% contours were presented to provide the fullest description of the location data obtained, and 95% contours were used to permit comparisons based on areas of more consistent use. Because all animals' home ranges were located along the shoreline, varying areas of open water were included in the initial 95% and 100% MCP values. Accordingly, the area of open water was determined using the geographic information system, and subtracted for the description and comparison of home range size.

RESULTS

Capture and Handling

Nine trapping sessions were conducted between June 1989 and April 1991 (Table 6). A total of 13 raccoons were captured, including 1 recapture. Overall trapping success was 0.7 captures per 100 trap-nights, where one trap-night (tn) was defined as one trap, open for one night.

Trapping success was lower on the Limestone Islands than on VP, presumably because fewer animals were present. In 836 tn, only one animal was captured on the Limestone Islands (0.1 captures/100 tn). On VP, 12 captures were made in 912 tn (1.3 captures/100 tn), a more than ten-fold difference.

Trapping success also varied within VP, where shoreline traps were more successful than inland traps. In 391 tn of grid trapping, only two animals were captured (0.5 captures/100 tn), and both of these were taken in shoreline traps. No raccoons were caught in traps set 250 m or more inland, and no signs of activity were observed at these traps. Conversely, in 521 tn from shoreline circuits, 10 raccoons were caught (1.9 captures/100 tn).

Trapping success varied seasonally, as indicated by trapline data from VP. Highest trapping success was achieved in March 1989, when 6 animals were captured in 180 tn (3.3 captures/100 tn). Trapping success from May to August ranged from 0 to 2.3 captures/100 tn. If the winter period in the QCI is characterized by limited food

Table 6. Trapping effort and success within study area, June 1989 to April 1991.

TRAPPING		TRAP-NIGHTS*					SUCCESS
SESSION	DATE	VP	EL	WL	Total	CAPTURES	(captures/100 trap-nights)
	1989						
1	Jun 9-18	269	0	0	269	2	0.7
2	Jun 22-29	182	0	0	182	1	0.5
3	Jul 3-7	88	0	0	88	2	2.3
	1990						
4	Mar 11-18	180	0	0	180	6	3.3
5	May 7-12	72	50	0	122	1 (VP)	0.8
6	May 21-26	90	50	0	140	0	0.0
7	Aug 3-7	31	0	0	31	0	0.0
	1991						
8	Mar 17-Apr 17	0	427	103	530	1 (EL)	0.2
9	Apr 9-18	0	206	0	206	0	0.0
TOTAL TRAP-NIGHTS		912	733	103	1748		
TOTAL CAPTURES		12	1	0		13	
SUCCESS		1.3	0.1	0.0			0.7

*VP=Vertical Point; EL=East Limestone; WL=West Limestone.

resources, this may render raccoons most susceptible to trapping in early spring, when fat reserves are low.

Most captured animals were successfully collared with radio transmitters: all measurements and handling details are presented in Appendix C. Two males convulsed from 7-9 minutes following injection, and heavy salivation was noted in two instances. These are documented side effects of ketamine (Plumb 1991:92-95), which can be reduced by adding the sedative, xylazine (H. Schwantje DVM, pers. comm.).

Three of 12 animals were not successfully collared and/or monitored. One female (F65) probably dropped her collar within a few days of handling, based on subsequent observations of collar size and the raccoons' ability to remove them. A second female (F*a*) was deemed too small to collar, and was ear-tagged only. A third female (F*b*) was ear-tagged and given a simple reflective collar for visual identification. Because of the thin and pliable nature of this collar, the female was able to remove it while in the recovery bucket (a fact not determined until the animal was released!).

QCI raccoons were similar in size to those of the southern and eastern states, but smaller than those in the central and northern part of their range (Cowan 1973). Body masses of males (X +/- SD = 4.9 +/- 0.9 kg, n=6) and females (4.0 +/- 0.8 kg, n=7) were similar. However, valid comparisons rest on the separation of yearlings and adults, which was not done in this study. No teeth were removed, but tooth-wear ranged from minimal to very pronounced, suggesting that animals of different ages were captured (Grau et al. 1970).

Home Range Size and Location

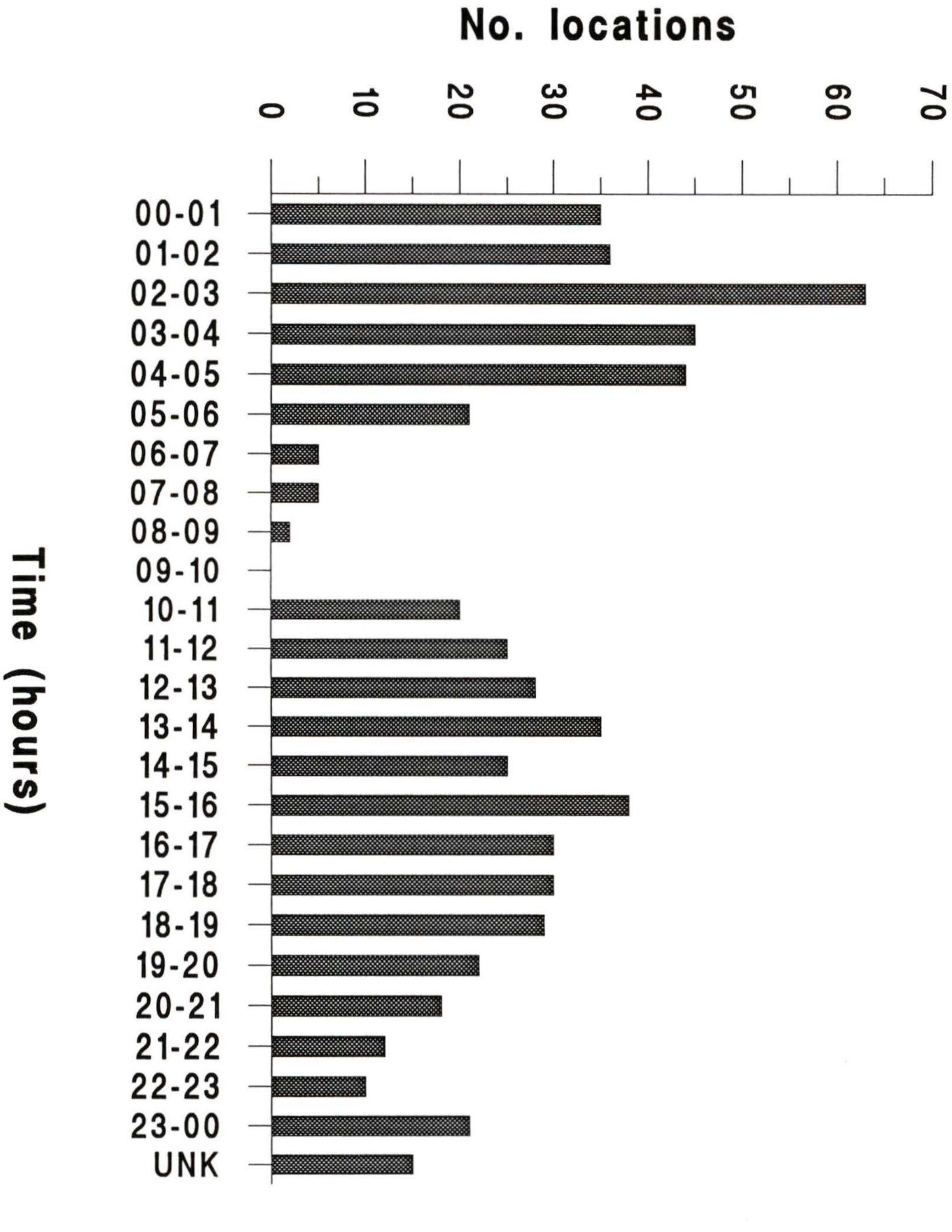
Nine animals were located 614 times, including 256 sightings, over several seasons (Table 7). Locations were distributed throughout the 24-hour day (Fig. 6),. The four animals (2M, 2F) captured in 1989 were monitored over two summer sessions, and one brief winter session. Because of the limited sample size, winter locations are not presented separately, but are combined with the multi-annual home ranges. Of these animals, one male (M35) was also sighted in spotlight surveys throughout the third and final summer, his transmitter having expired. The four animals (3M, 1F) captured in 1990 were tracked for one session only, as was F05, captured in 1991.

A plot of cumulative home range size as a function of increasing sample size indicated that for the 4 animals monitored over two years, home range size reached an asymptote after

Table 7. Number of locations obtained for all study animals from 1989-1991, according to field season (S=summer, W=winter).

ANIMAL	SEASON	NUMBER OF LOCATIONS DAY	NIGHT	TOTAL
M75	89S	25	13	38
	89W	2	4	6
	90S	13	23	36
	89-90	*40*	*40*	*80*
M35	89S	29	20	49
	89W	3	2	5
	90S	33	33	66
	91S	0	9	9
	89-91	*65*	*64*	*129*
F85	89S	32	21	53
	89W	2	3	5
	90S	17	18	35
	89-90	*51*	*42*	*93*
F15	89S	25	30	55
	89W	3	6	9
	90S	17	24	41
	89-90	*45*	*60*	*105*
M45	90S	13	24	37
M25	90S	11	19	30
M95	90S	20	9	29
F55	90S	21	29	50
F05	91S	37	24	61
TOTAL		303	311	614

Figure 6. Hourly distribution of animal locations obtained throughout the study.


No. locations
0
10
20
30
40
50
60
70
Time (hours)
00-01
01-02
02-03
03-04
04-05
05-06
06-07
07-08
08-09
09-10
10-11
11-12
12-13
13-14
14-15
15-16
16-17
17-18
18-19
19-20
20-21
21-22
22-23
23-00
UNK

approximately 30-40 locations (Fig. 7)(open water was not excluded from this analysis). A complete shift in the home range of raccoon M35 is also evident in Figure 7, beginning with location 47. Within the new area, home range size again levelled off within approximately 20 locations. The five animals monitored for only one season showed a similar pattern, which suggests that the data are adequate to permit comparisons of home range size among study animals.

Home ranges were small (Table 8). The 100% MCP home range for males (X +/- S.D.), excluding open water, was 60 +/- 23ha (range 32.0 - 96.6, n=7), that of females 28 +/- 8ha (range 17.1 to 39.5, n=6). Home ranges of males were significantly larger than those of females for both the 100% MCP ($0.005<P(|t|>3.2222)<0.01$) and the 95% MCP ($0.002<P(|t|>3.6207)<0.005$).

Home Range Constancy

Both of the females monitored over a period of two years demonstrated home range fidelity. In 1989, F15 occupied most of VP and concentrated her activities in and around the large bay on the south side of VP (Fig. 8a). The following year, her home range was similar, shifting slightly southeastward to include more of VP. Because the extension resulted from only two locations it does not provide evidence of a significant shift. In 1989, F85 concentrated her activities along the south shore of the study area. In 1990, there was no change in the portion of the shoreline used by this animal, and only a slight increase in the distance travelled inland to den.

The two males monitored during both 1989 and 1990 showed different patterns. M75 travelled widely within the study area early in 1989, before beginning to settle along the northern shore (Fig. 8b). In 1990, he used the northern part of the study area more consistently, which suggests that he may have been a young male in the process of establishing his range when first monitored. Raccoon M35, by contrast, completely shifted his home range location. This male was routinely located on VP from July until late September, 1989. He then swam to EL, established a home range which included the colony islands of EL and WL, and was not detected on VP for the rest of the study.

Winter locations

Between November 29 and December 11, 1989, 5-9 locations were obtained for each of the above 4 animals. While not true hibernators, raccoons do "hole up" for days or weeks in cold winter weather (Stuewer 1943, Mech et al. 1966, Berner and Gysel 1967). Within

Figure 7. Size (ha) of 100% MCP home range of four study animals, as a function of the number of locations (numbers in parentheses refer to years of study).

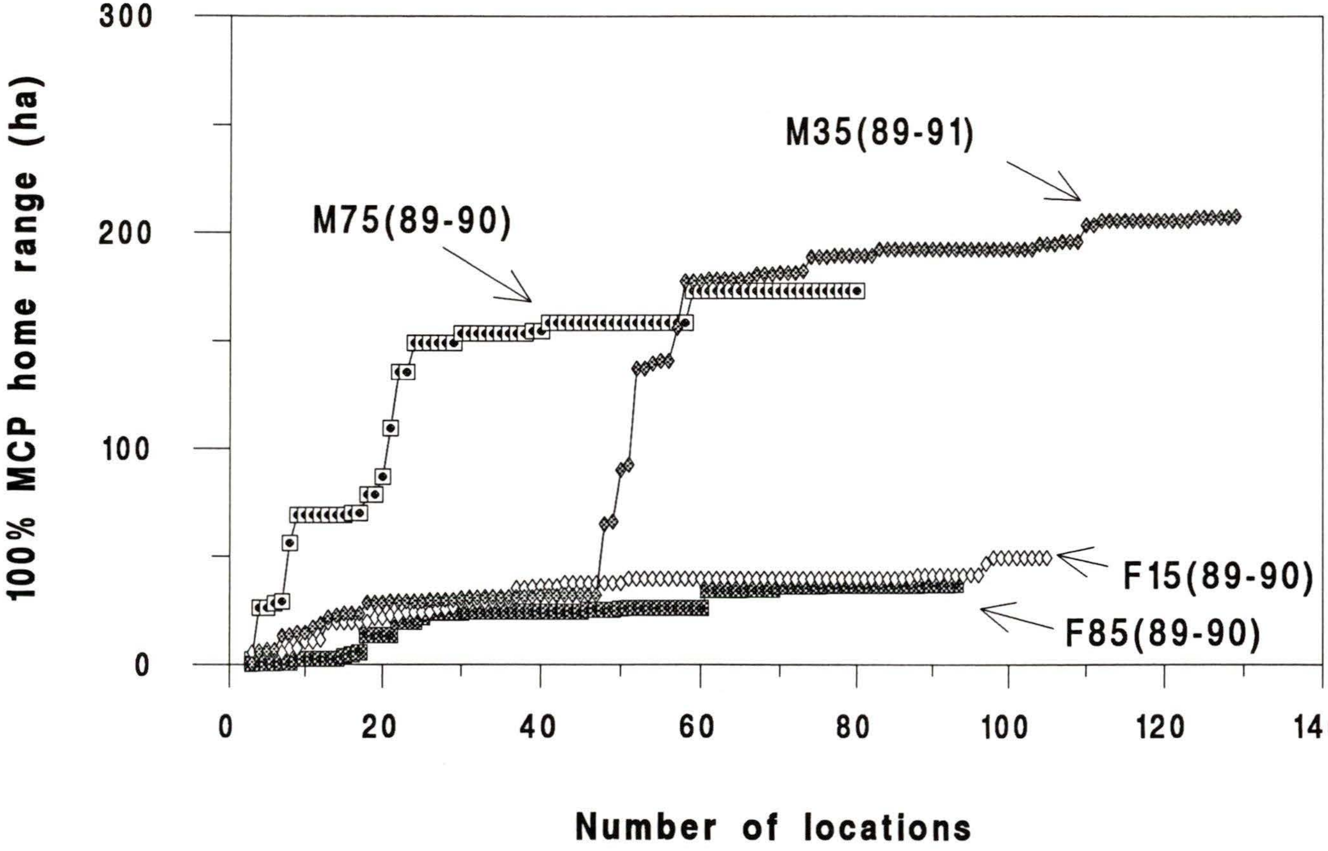

300
200
100
0
100% MCP home range (ha)
0
20
40
60
80
100
120
140
Number of locations
M75(89-90)
M35(89-91)
F15(89-90)
F85(89-90)

Table 8. Home range size* of monitored raccoons from VP and EL.

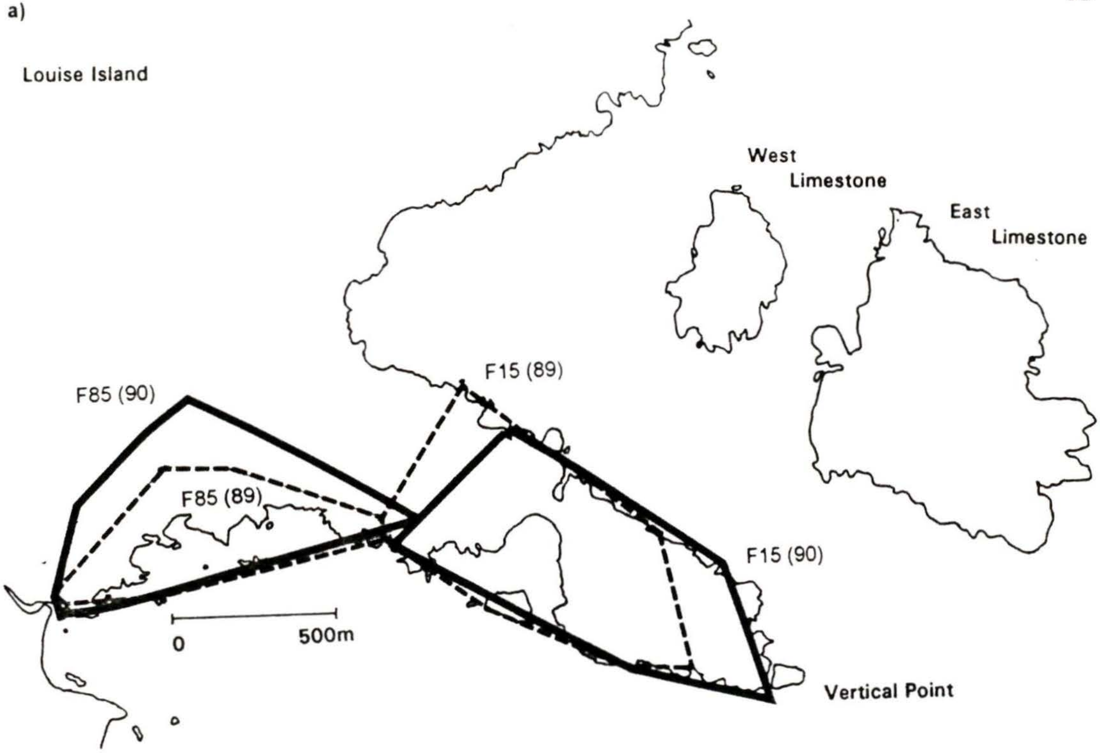
	MCP HOME RANGE (ha)	
STUDY ANIMAL (SEASON)	95%	100%
MALES		
M75 (89)	67.5	96.6
M75 (90)	35.8	59.4
M75 (89-90)	*84.8*	*116.3*
M35 (89)	27.7	32.0
M35 (90)	42.6	51.4
*M35 (89-91)***	*84.9*	*90.7*
M95 (90)	38.7	44.9
M45 (90)	47.6	85.9
M25 (90)	33.2	51.1
FEMALES		
F15 (89)	26.8	32.6
F15 (90)	23.5	33.5
F15 (89-90)	*31.8*	*40.9*
F85 (89)	9.3	17.1
F85 (90)	21.4	24.0
F85 (89-90)	*23.8*	*27.7*
F55 (90)	22.3	23.1
F05 (91)	22.2	39.5
SEASONAL HOME RANGE OF MALES (X+/-SD)	41.9 +/- 13.0	60.2 +/- 23.0
SEASONAL HOME RANGE OF FEMALES (X+/-SD)	20.9 +/- 6.0	28.3 +/- 8.3

* excluding open water

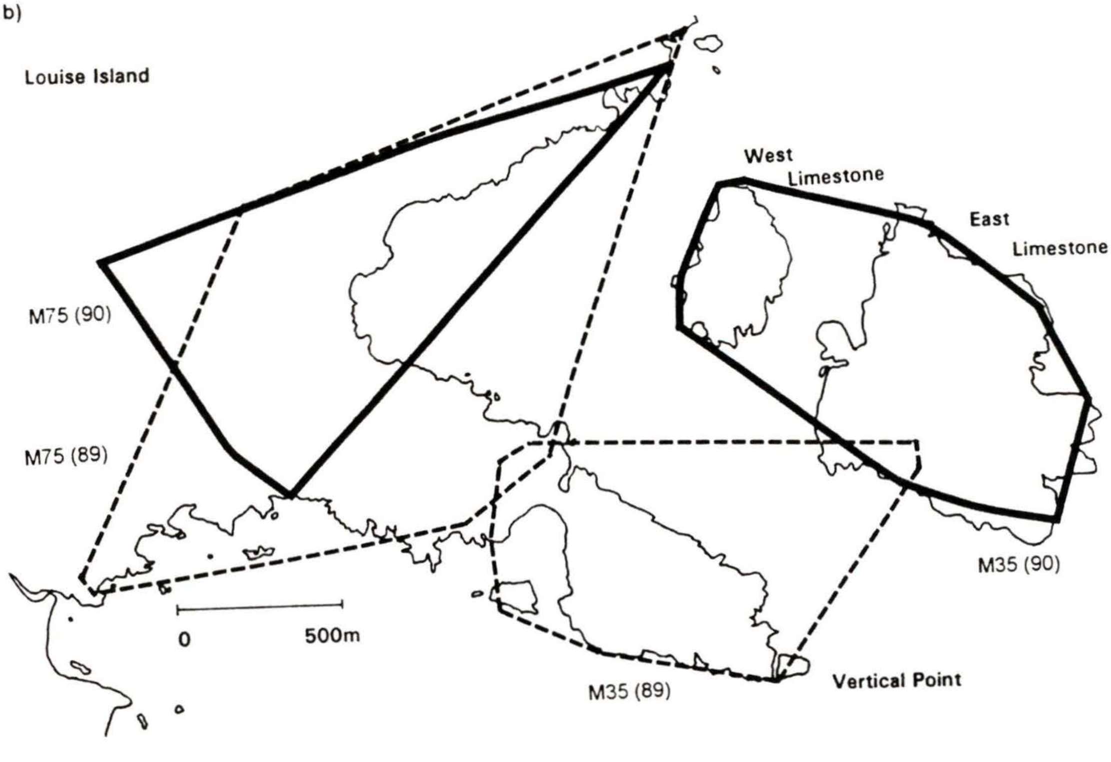
** includes 9 night locations from the 1991 season.

Figure 8. Home range fidelity of a) two female and b) two male raccoons, monitored in the summers of 1989 and 1990, based on 100% MCP estimates (numbers in parentheses refer to years of study).

a)


Louise Island
West
Limestone
East
Limestone
F15 (89)
F85 (90)
F85 (89)
F15 (90)
0
500m
Vertical Point

b)


Louise Island
West
Limestone
East
Limestone
M75 (90)
M75 (89)
M35 (90)
0
500m
M35 (89)
Vertical Point

this brief monitoring period, however, all animals were active every night. Mean minimum temperatures for Sandspit ranged from 3.5-5.2 C during this period (Environment Canada unpubl. data), well above the -5 to -15 C during which "holing up" has been documented elsewhere (Sharp and Sharp 1956, Mech et al. 1966, Schneider et al. 1971), and no snow fell within the study area.

Winter locations for F15, F85 and M75 were within the boundaries of the home range documented for the previous summer (1989). Locations for M35 were obtained on both EL and WL, and on the cliffs of Louise Island due north of WL. The sequence in which these locations were obtained indicated that M35 made at least 5 water crossings of 150 to 300 m between December 7-11. Sea surface temperatures were not recorded, but were available from 3 lighthouse stations in this region, Langara, Bonilla and Cape St. James Islands (Freeland 1990). Mean December temperatures at these sites were 8.1 C, 8.4 C and 9.1 C respectively, approximately 1 C warmer than the longterm December averages (H. Freeland, pers. comm.). Waters were often calm during this field session.

Home range overlap

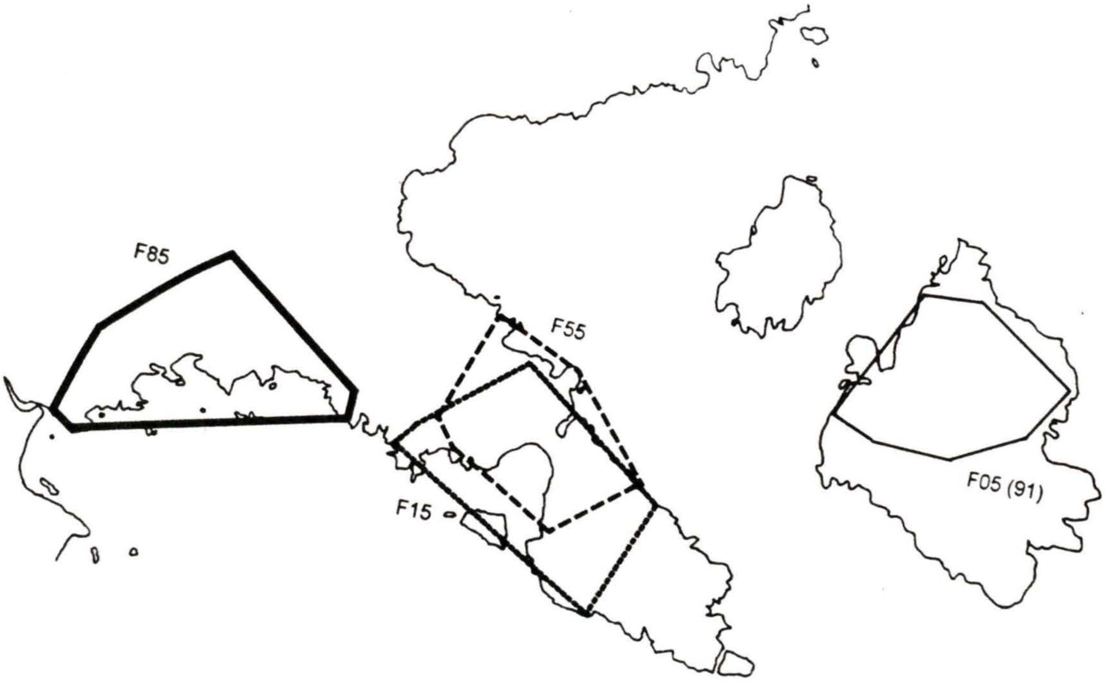
Within both sexes, home ranges for some individuals overlapped, and those of others did not. Home ranges of F85 and F15 abutted but did not overlap in either 1989 or 1990 (Fig. 8a); both females were accompanied by kits in 1989 only. In 1990, the small home range of F55 fell almost entirely within that of F15 (Fig. 9a). These animals were observed foraging together at least 6 times, and on several occasions in the spring they appeared to be denned in the same place. This close association suggests that F55 may have been the yearling offspring of F15.

M35 and M75 showed no overlap in 1989. By 1990, M35 had colonized EL, and an additional 3 males were collared on VP (Fig. 9b). Of the 4 collared males on VP, M45 and M75 maintained home ranges with extensive overlap. They were frequently observed foraging together, but were not recorded as denning in the same place. No overlap occurred between the home ranges of these two males, and those of M25 or M95, nor between the home ranges of the latter two males.

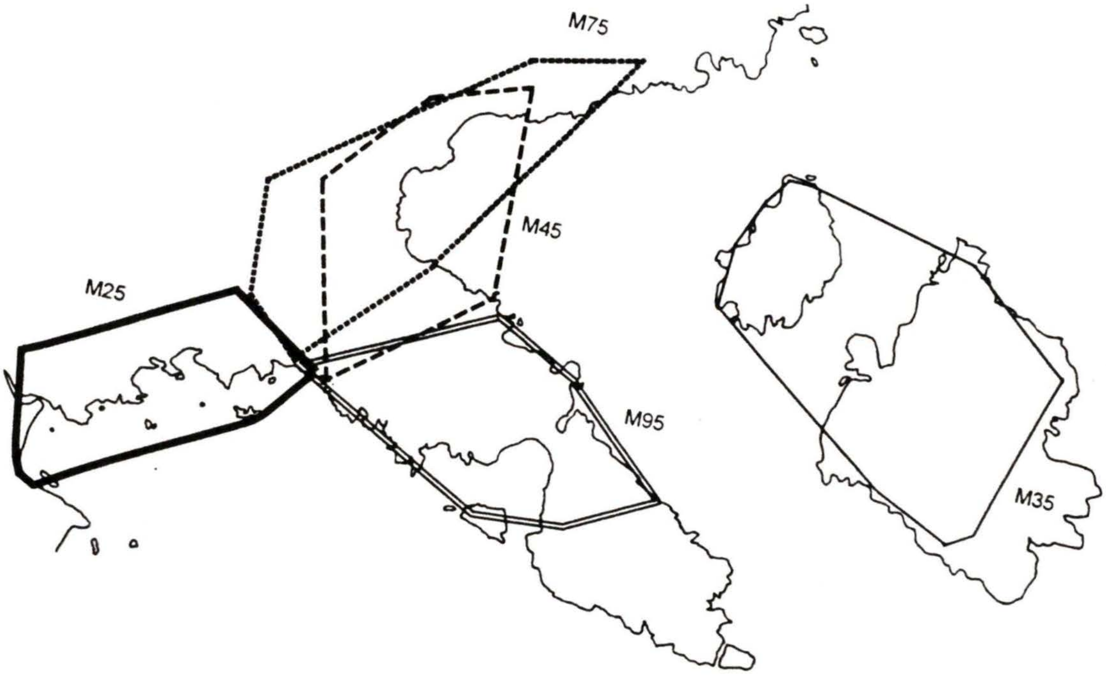
Home ranges of all monitored females overlapped with that of at least one male. In 1990, the home range of M95 overlapped with those of F15 and F55, and the home range of M25 overlapped that of F85. In 1991, EL was occupied by both F05 and M35. Within the group of monitored animals, home range overlap between sexes appeared more

Figure 9. Overlap in the home ranges of a) 4 female and b) 5 male raccoons, in 1990, based on 95% MCP estimate (numbers in parentheses refer to years of study).

a)



b)



extensive than that within sexes, but both types were observed.

Patterns of Activity and Habitat Use

Raccoons exhibited a nocturnal pattern of activity on both VP and EL (Fig. 10). Of 304 day locations, raccoons were inactive during 231 (76%) and active for only 32 (11%). In the remaining 41 cases (13%), activity could not be accurately determined from the signal. Of 301 night locations, raccoons were active during 281 (93%), and inactive on only 11 occasions (4%). Activity could not be accurately determined from the signal in 9 of 301 cases (3%).

Although all monitored animals were active at night, the location of nightly activity differed between VP and EL. Raccoons at VP were almost always located foraging on the beach at night (Figs. 11-14). This pattern was evident in all of the home ranges documented, indicating a very consistent pattern among individuals. Of 241 night locations obtained for animals on VP, 226 (94%) were located on or within 50m of the shoreline, almost all of these on the beach itself.

Raccoons on EL were located inland at night significantly more often (19 of 39 locations) than raccoons at VP (15 of 226 locations) ($X^2 = 30.1$, $P<0.001$). This pattern was most evident in the locations of F05, found inland (<50m from shore) for only 41% of all active night locations, and active within the colony 41% of the time (Fig. 15a). The shift from shoreline to inland activity was less pronounced for M35, located inland for 17% of all active night locations, and <50m from shore the remainder of the time (Fig. 15b).

Unlike VP raccoons, not all of the locations obtained for M35 within 50m of shore reflected foraging activity on the beach. Of 11 spotlight sightings of M35 in 1990, 7 were at the vegetation line. Raccoons sometimes travel from the beach to the vegetation line when disturbed, but this was recorded for only 10% (n=84) of all raccoon sightings along the shoreline of VP in 1990. Possibly M35 was more easily disturbed from the beach than VP raccoons, because he was monitored more intensively. It is equally possible, however, that M35 was not foraging on the beach when located near the vegetation line, but rather was following the forest margin, and making forays into the colony area. This possibility is supported by one direct observation of M35 preying on a seabird at the edge of the forest (Chapter 3).

Generally, raccoons denned near the shore (Fig. 16). Of 230 day locations of inactive

Figure 10. Diel activity pattern of radio-collared raccoons.

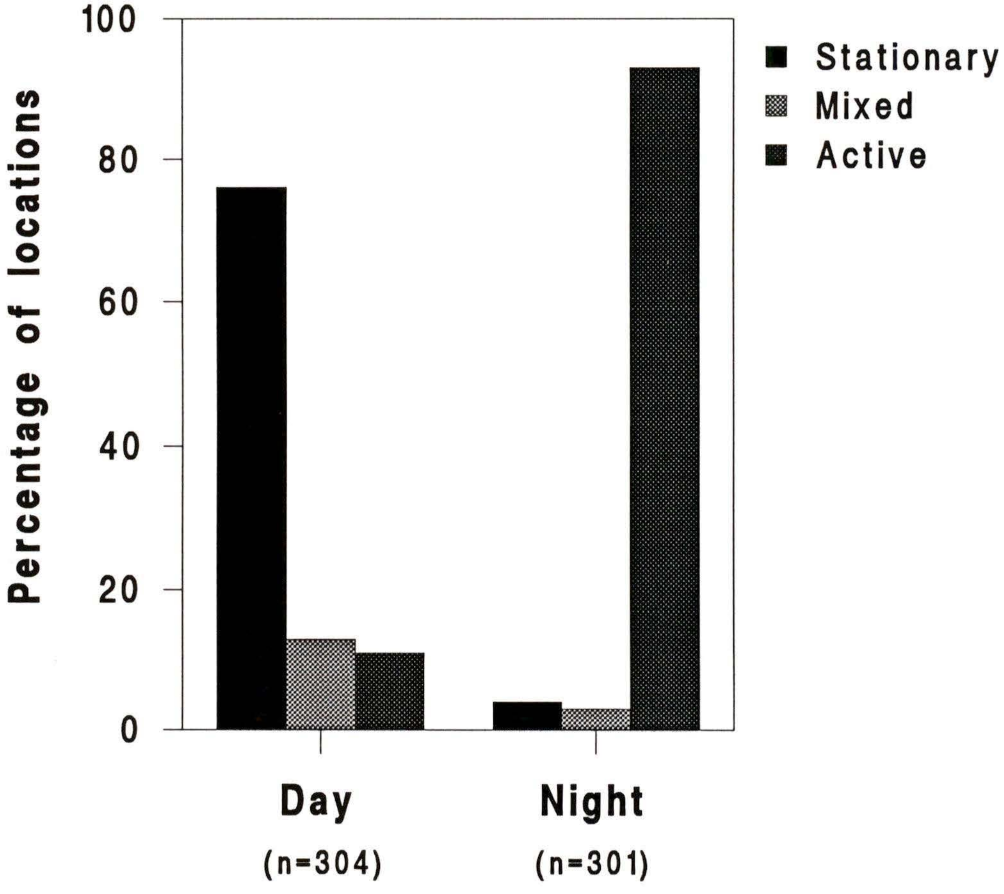
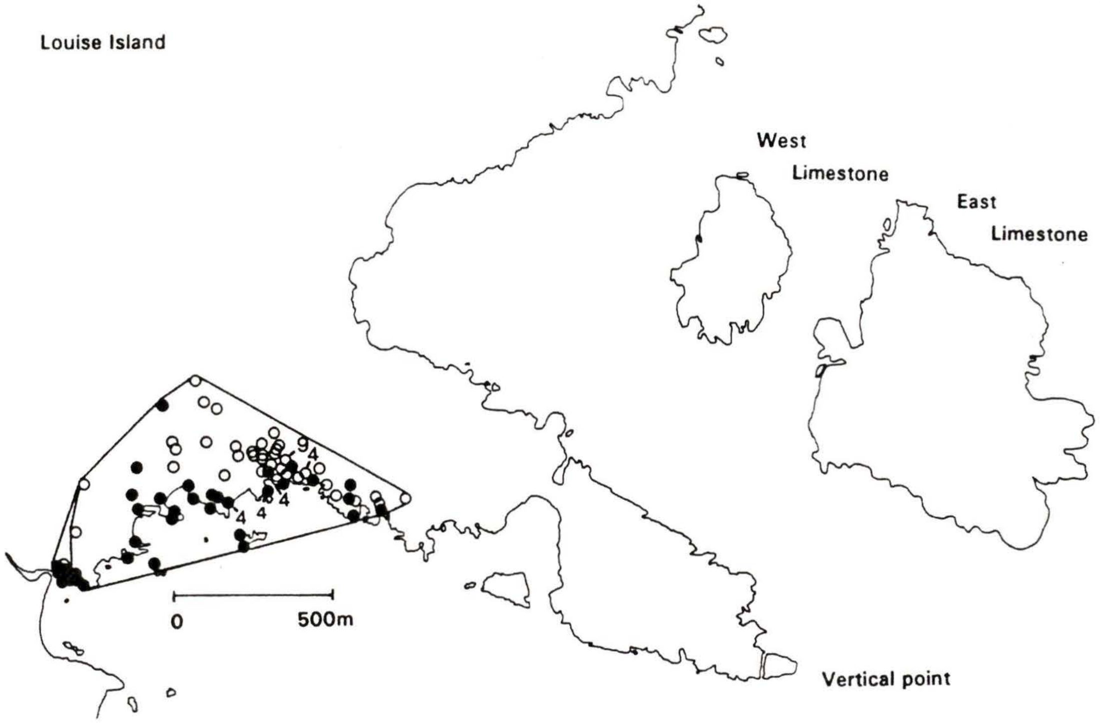

Percentage of locations
100
80
60
40
20
0
Stationary
Mixed
Active
Day
(n=304)
Night
(n=301)

Figure 11. Day (open circles) and night (closed circles) locations of raccoons in the absence of breeding seabirds: a) raccoon F85 (1989-90), b) raccoon F15 (1989-90).

a)


Louise Island
West Limestone
East Limestone
9
4
4
4
4
4
0
500m
Vertical point

b)

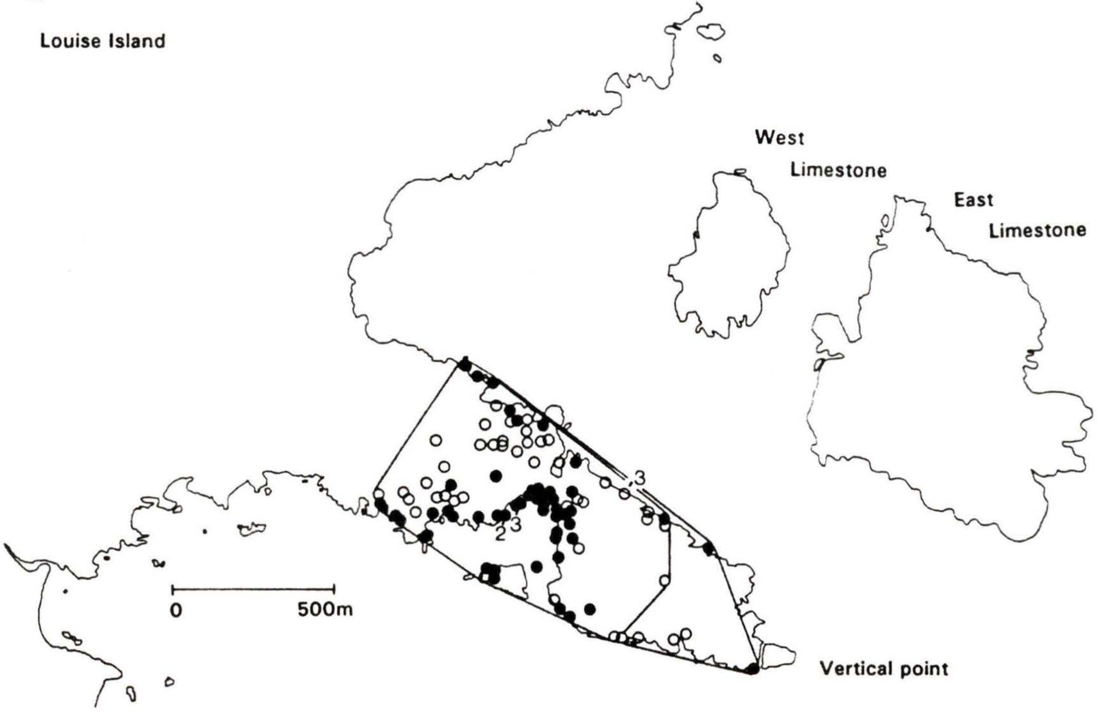
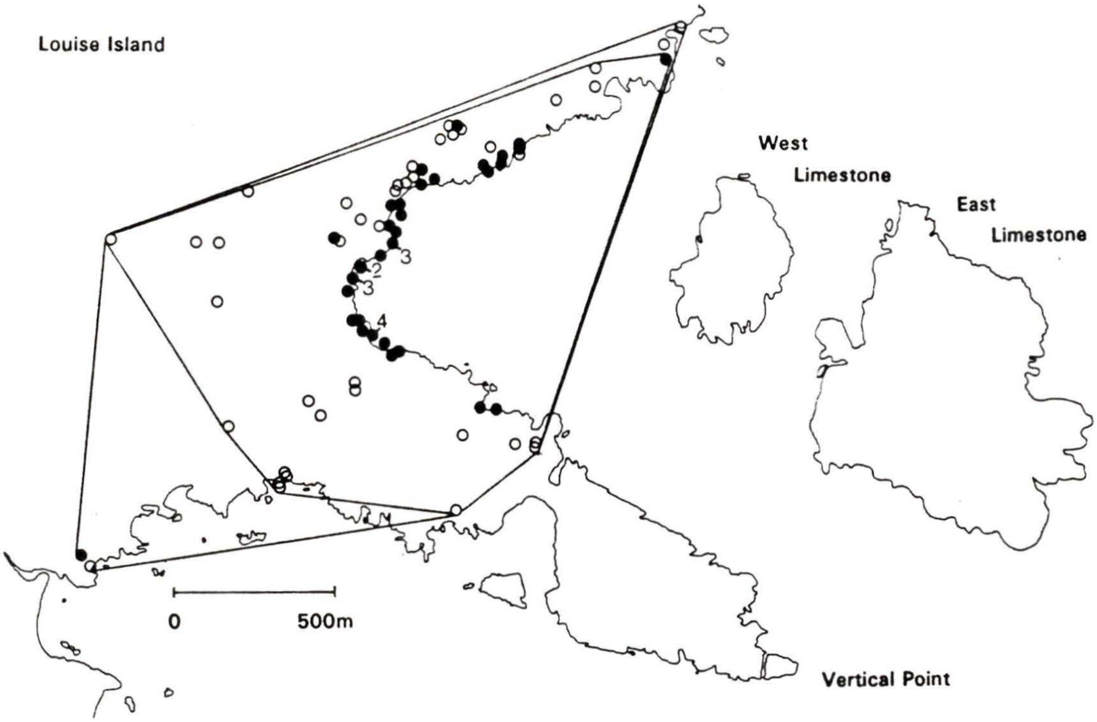

Louise Island
West Limestone
East Limestone
3
2
3
0
500m
Vertical point

Figure 12. Day (open circles) and night (closed circles) locations of raccoons in the absence of breeding seabirds: a) raccoon M75 (1989-90), b) raccoon M35 (1989-90).

a)


Louise Island
West
Limestone
East
Limestone
3
2
3
4
0
500m
Vertical Point

b)

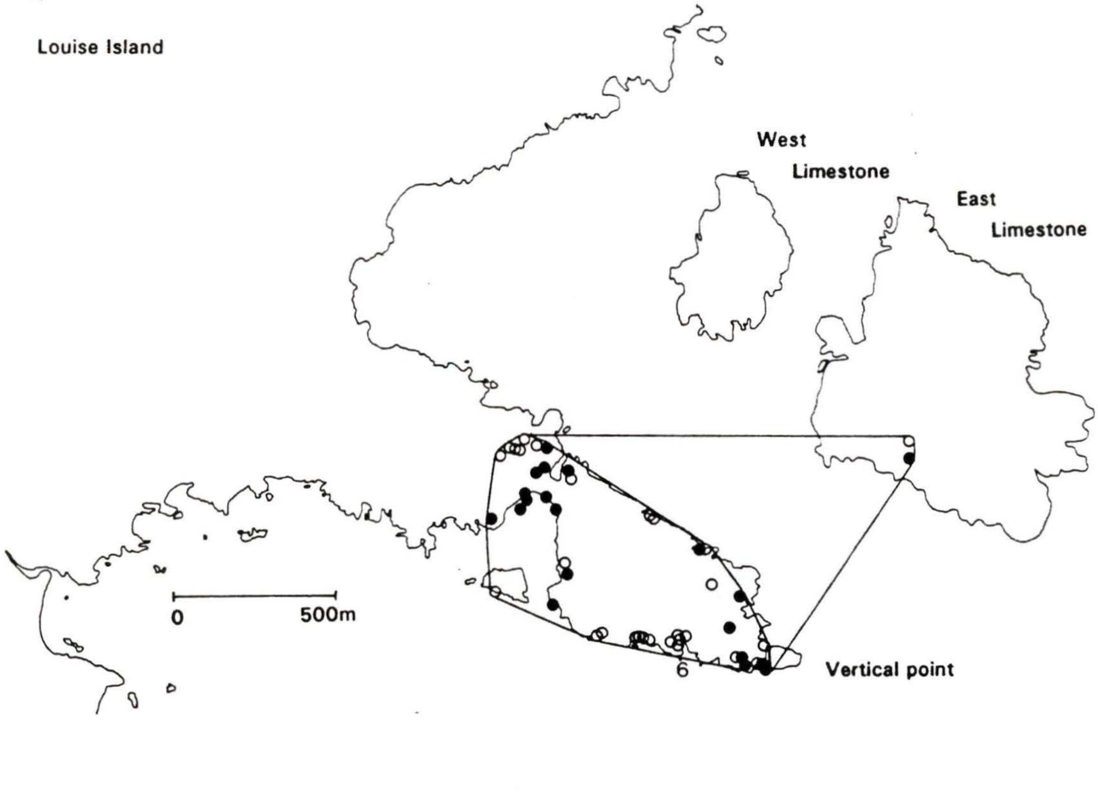

Louise Island
West
Limestone
East
Limestone
0
500m
6
Vertical point

Figure 13. Day (open circles) and night (closed circles) locations of raccoons in the absence of breeding seabirds: a) raccoon M25 (1990), b) raccoon M45 (1990).

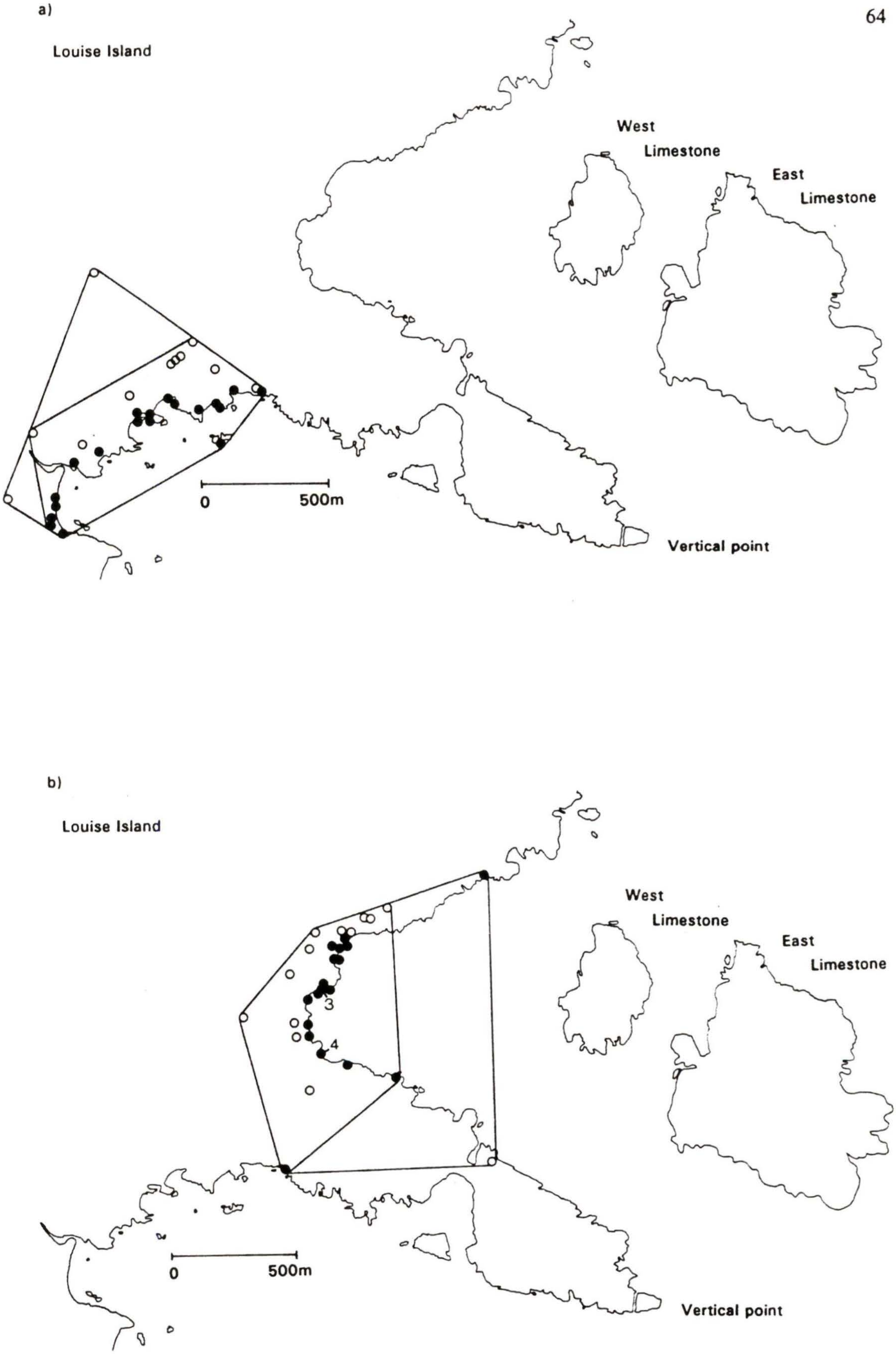
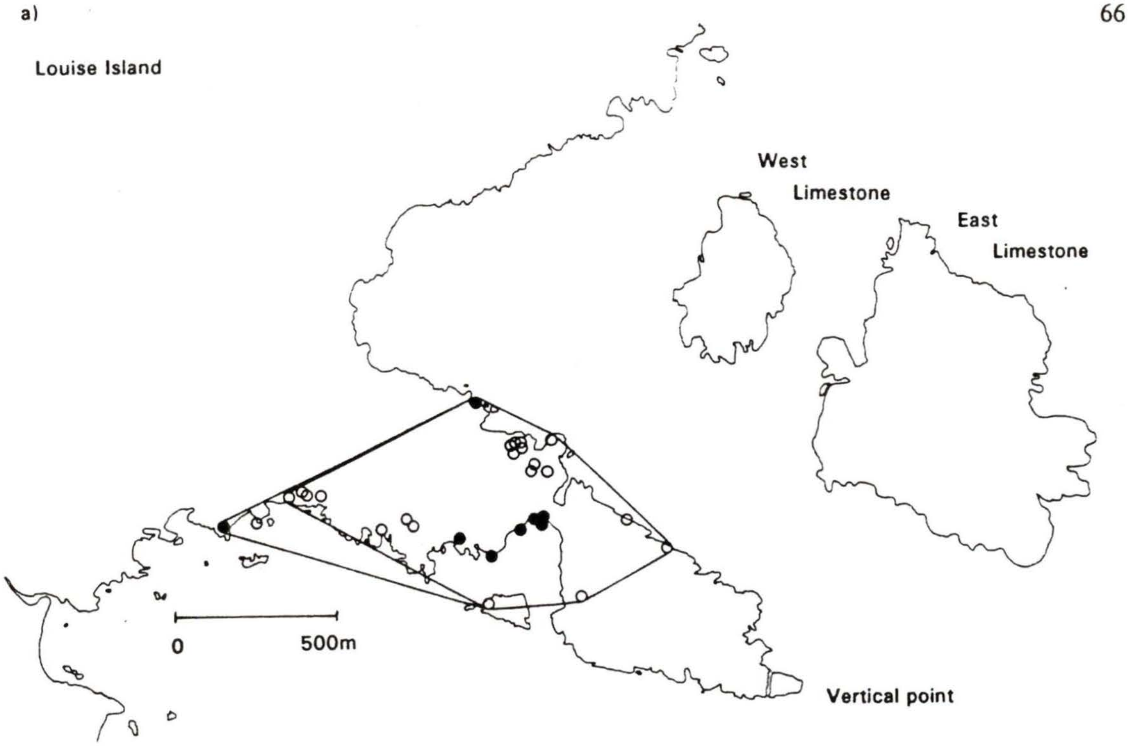

a)
Louise Island
West
Limestone
East
Limestone
0
500m
Vertical point
b)
Louise Island
West
Limestone
East
Limestone
3
4
0
500m
Vertical point

Figure 14. Day (open circles) and night (closed circles) locations of raccoons in the absence of breeding seabirds: a) raccoon M95 (1990), b) raccoon F55 (1990).

a)


Louise Island
West
Limestone
East
Limestone
0
500m
Vertical point

b)

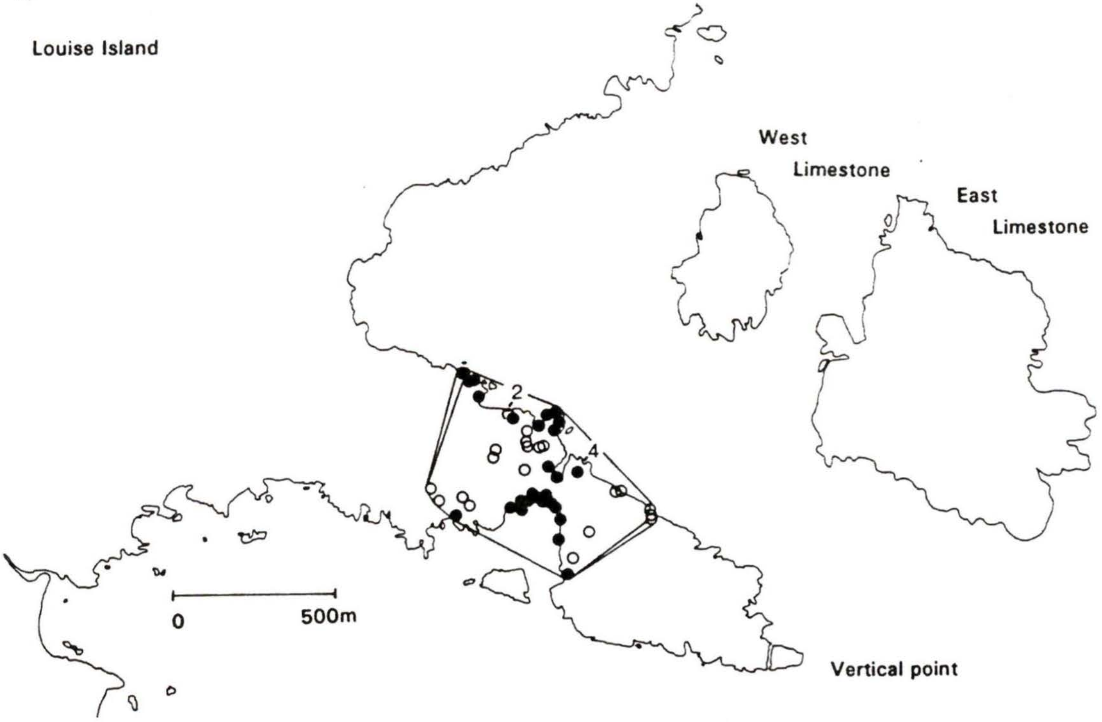
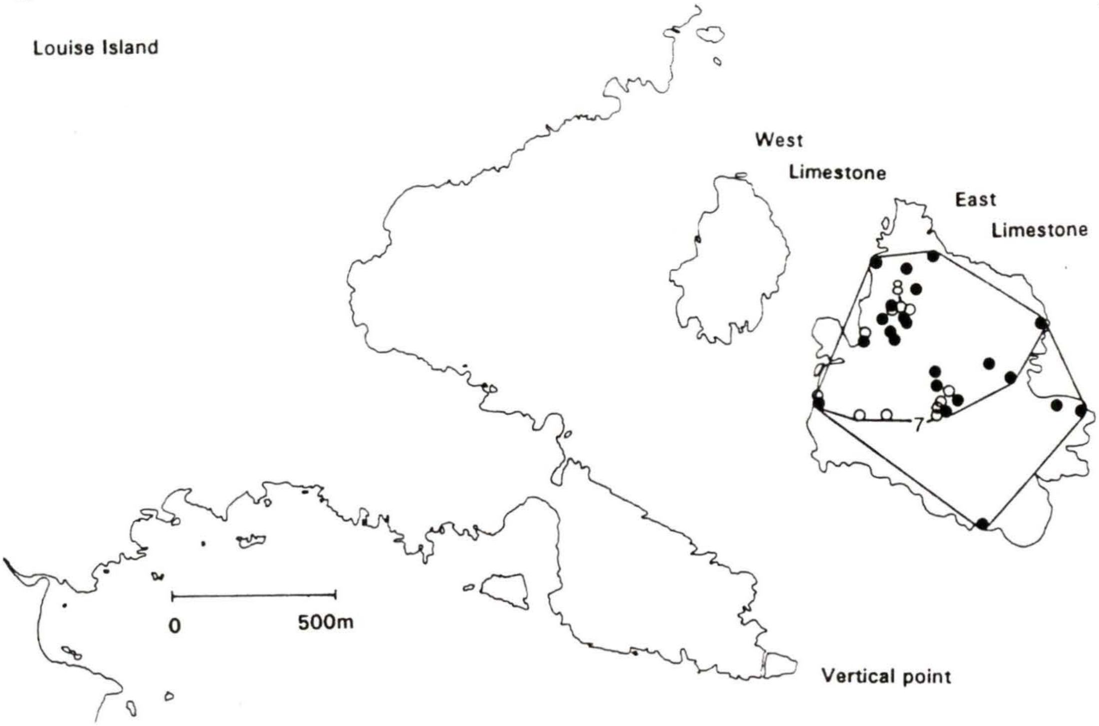

Louise Island
West
Limestone
East
Limestone
2
4
0
500m
Vertical point

Figure 15. Day (open circles) and night (closed circles) locations of raccoons in the presence of breeding seabirds: a) raccoon F05 (1991), b) raccoon M35 (1990).

a)


Louise Island
West
Limestone
East
Limestone
7
0
500m
Vertical point

b)

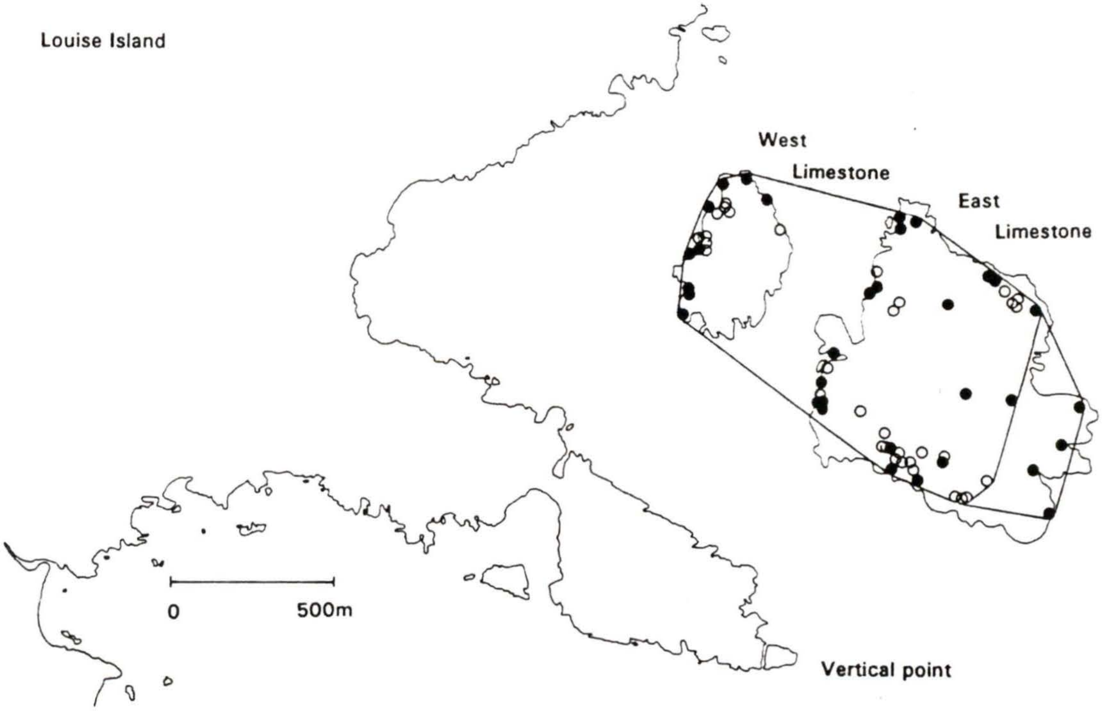
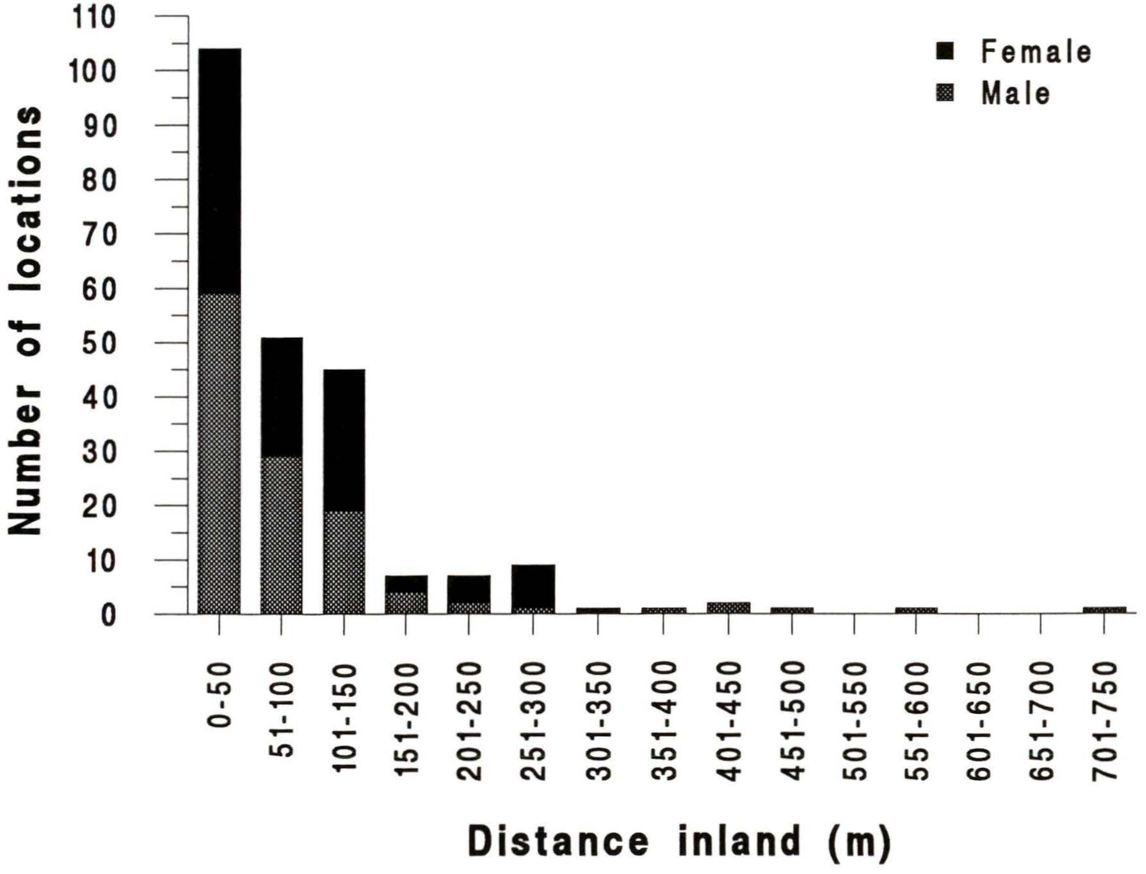

Louise Island
West
Limestone
East
Limestone
0
500m
Vertical point

Figure 16. Number of inactive (denned) radio-locations as a function of distance inland, for all monitored raccoons, 1989-91.


Number of locations
110
100
90
80
70
60
50
40
30
20
10
0
■ Female
▨ Male
0-50
51-100
101-150
151-200
201-250
251-300
301-350
351-400
401-450
451-500
501-550
551-600
601-650
651-700
701-750
Distance inland (m)

raccoons, 87% were within 150m of shore. The remaining 13% of locations occurred up to 750m inland (Fig. 16). Male raccoons did not re-use den sites on either VP or EL. This suggests thatden sites were not in short supply. Females sometimes re-used den sites, and the extent of re-use varied among individuals. F15 used one den site for three consecutive days in 1989, but was not observed to re-use den sites on any other occasion. F85 used one den site at least 11 times in July 1989. Because she was later observed with three young, that site was probably a maternal den. F05 concentrated denning activity within two locations, using both sites approximately 20 times each. These dens were also thought to be maternal dens, because F05 was later seen accompanied by at least one young.

Detailed descriptions of den sites were not attempted. In 7 cases, however, den sites were encircled in the course of telemetry. Three of these dens were in tree cavities, one in the base of a large stump, two in either a tree or its root mass, and one in a ground cavity. Raccoons therefore used a variety of cavities, which were abundant within the forest, for denning. Denning often occurred within steep habitat, defined as having a slope classification of 8-10, or greater than 46% (Walmsley et al., 1980). As steep slopes and cliffs parallel the shoreline of much of the study area, it is unclear whether it was slope or proximity to the beach which influenced the raccoons to den there.

Shoreline Distance

Because of the importance of the shoreline for foraging, shoreline distance encompassed within each animals' home range was measured, following the waterline on a 1:5,000 map (Table 9). Whereas home range area differed significantly between males and females, the shoreline distance encompassed within home ranges did not. Although males tended to have a greater extent of shoreline habitat within their home ranges than females, this difference was not significant for either the 100% ($0.20<P(|t|>1.3187)<0.50$) or 95% MCP home ranges ($0.20<P(|t|>0.8739)<0.50$).

Table 9. Shoreline distance (m) encompassed in 95% and 100% MCP home ranges of male and female raccoons from VP and EL.

MCP HOME RANGE				
95%	100%	n	X +/- SD	RANGE
Male		7	2790 +/- 1260	1200 to 4520
Female		6	2280 +/- 725	1660 to 3280
	Male	7	3785 +/- 1590	2025 to 6245
	Female	6	2750 +/- 1160	1825 to 4695

DISCUSSION

The potential impact of raccoons on seabirds of the QCI depends in part upon the raccoons' ability to survive on offshore colony islands. It further depends upon the extent to which the raccoon's patterns of movement and habitat use place them in contact with breeding seabirds. Results of this study indicate that several features of the raccoon's home range and habitat use patterns are conducive to their survival on colony islands, and contribute to a high probability of contact with breeding seabirds.

Coastal raccoons of the QCI maintain relatively small home ranges, averaging 28 ha for females and 60 ha for males. These home range sizes fall near the low end of values reported in the literature. The largest raccoon home ranges have been documented in an agricultural region of North Dakota, with averages of 656-2560 ha (Fritzell 1976). The smallest home ranges have been reported for urban areas, with averages of 5-37 ha (Cauley and Schinner 1973, Hoffman and Gottschang 1977, Sherfy 1980). Most studies, however, have reported home ranges of 50-200 ha (Stuewer 1943, Cunningham 1962, Johnson 1970, Urban 1970, Shirer and Fitch 1970, Fleming 1971, Glueck et al. 1988).

In general, the smaller the area within which raccoons meet their basic requirements, the greater the number of islands of the QCI on which they can establish resident populations. Although home range varies between individuals, sexes, and habitats, the presence of resident raccoons on the Limestone Islands (combined area = 59 ha), and the documented average home range size of raccoons on VP (60 ha for males), can serve as guidelines to the size of island capable of sustaining raccoons. Of the 1.5 million burrow-nesting seabirds on the QCI, 78% breed on islands or island clusters of >56 ha (Rodway et al. 1988). Not all such islands are known to be accessible, nor do they necessarily contain adequate resources to support raccoons, but they are of a size which supports resident animals on EL.

Home ranges of males were significantly larger than those of females, as has been found in other studies (Schnell 1969, Fritzell 1976, Hoffman and Gottschang 1977 and Sherfy 1980). The average spring-summer home range of male raccoons was roughly double that of females. For the male and female monitored on the Limestone Islands, this difference was manifested by the inclusion of both EL and WL by the male, compared with the occupation of only EL by the female. The larger home range area used by males may thus be one factor determining which islands raccoons colonize.

Although home range size varied significantly between sexes, the mean extent of shoreline foraging habitat within the home range of VP raccoons did not. The shoreline distance did vary widely among study animals, however, which may indicate that the extent of shoreline encompassed within the home range is influenced by the quality of the component habitats, as well as the varying requirements of animals differing in size and reproductive status. If so, the quality and extent of shoreline habitat may be one factor determining which islands raccoons colonize, what density they attain, and how severely they prey on breeding seabirds. The relationship between the quality of shoreline habitat for foraging and the amount encompassed within the home range would be an interesting topic for future research.

Few authors have reported on home range fidelity. Two adult females monitored over two spring-summer seasons at VP demonstrated a high degree of home range fidelity, consistent with the observations of Fritzell (1976) for parous female raccoons in North Dakota. Such fidelity is likely to contribute to greater familiarity with the home range, and hence an increased ability to encounter and exploit seasonally available food resources such as breeding seabirds.

The extent to which adult males occupy the same area from year to year is less clear. Lotze (1979) reported a gradual shift in the home range of one male raccoon, monitored for 4 years, but portions of the range overlapped consistently among years. In this study, the ages of collared animals were unknown; thus, it is impossible to distinguish between lack of home range fidelity, and the exploration and dispersal characteristic of juveniles. Of two males monitored for two seasons, one restricted its home range in the second year, whereas the second made a complete shift. As both appeared to be young at the time of capture, they may have been in the process of establishing home ranges (Fritzell 1976). The difference in the patterns of exploration observed for these two animals highlights the role of individual behavioural differences in the colonization of seabird islands.

Home range overlap has been reported for raccoons of different sex and age classes (Stuewer 1943). In this study substantial home range overlap within sexes was not recorded, except for two pairs of animals (M/M and F/F) repeatedly observed together, and thought to be related. Such lack of overlap may well have been a sampling artifact, as repeated spotlight surveys of VP indicated 2-3 times as many uncollared as collared raccoons. Also, where food is abundant, large numbers of raccoons come together to feed (Sharp and Sharp 1956, Lowery 1974). The non-territorial behaviour of raccoons probably permits them to reach greater densities on islands than would be attained by territorial species with similar habitat requirements.

In this study, den site selection was not studied in detail. Raccoons have been reported to den in a diverse array of natural and man-made cavities, including hollow trees (Stuewer 1943, Sherfy 1980), buildings (Cowan 1973), muskrat lodges (Urban 1970), artificial nest boxes (Baker and Newman 1942), ground burrows (Shirer and Fitch 1970), and rock crevices (Giles 1942). Several authors have also reported surface rest sites for raccoons (Dorney 1954, Mech et al. 1966, Schneider et al. 1971, Ivey 1948). Although the choice of den site(s) is generally made on the basis of availability, factors such as age, sex and season also have an influence (Rabinowitz and Pelton 1986, Endres and Smith 1993).

Incidental observations at VP and EL indicated that raccoons had access to, and used, a variety of den types. The forested habitat of the study area contained many large trees and stumps, as well as cavities within root masses, cliffs and windfalls. Stuewer (1943) provided evidence that where denning sites were abundant, those within approximately 400 m of water were used first. As most denning at VP and EL occurred within less than 150m of shoreline, and as animals were seldom observed re-using den sites on consecutive nights, den sites were probably not limiting. In this respect the habitat within the study area was typical of that found along much of the coast of the QCI.

Raccoons are predominantly nocturnal, but are occasionally active in daylight (Stuewer 1943, Sharp and Sharp 1956, Cunningham 1962, Urban 1970, Fleming 1971, Schneider et al. 1971, Lowery 1974, Fritzell 1976, and Glueck et al. 1988). The activity of raccoons monitored on both VP and EL was consistent with this pattern. No evidence was found that these coastal raccoons had adapted to "a specialized schedule which consists of activity at low tide and inactivity at high tide, almost without regard for day or night." (Ivey 1948). In Ancient Murrelets, the arrival and departure of breeding birds, as well as their courtship, fighting and burrow excavation all occur at night, beginning about 2 h after sunset (Gaston 1992). Thus, the nocturnal activity of raccoons overlaps completely the period of greatest activity within the murrelet colony.

Use of shoreline habitat differed for raccoons at VP and EL. On VP, both the study of diet (Chapter 1) and the observed distribution of day and night locations indicated almost exclusive foraging on the beach. The complete lack of trapping success inland provides further support for this. The consistency with which raccoons were located along the shoreline suggests that animals travelled there directly, and remained there for most of their active period. Urban (1970) found that raccoons in marsh habitat typically moved "considerable distances...over short time periods, followed by long periods of time spent in small areas where shallow water was present". Directed movements were also typical of raccoons studied in an urban environment, where raccoon movements were largely restricted to travel between their den sites and feeding areas (Cauley and Schinner 1973, Hoffman and Gottschang 1977). This type of movement is likely a response to a concentrated and predictable food source. Moreover, the similarity in the behaviour patterns of all collared animals at VP suggests that few foraging alternatives offered equivalent rewards.

On EL, raccoons spent the nights at the edge of the forest, or within the colony itself, rather than on the beach. This shift in the location of activity was most obvious for raccoon F05, the majority of whose locations were within the seabird colony. M35 was not located inland as frequently as F05, but similarly was not located on the beach with the regularity of VP raccoons. Although neither of these animals were monitored extensively on EL when seabirds were absent, M35 did conform to the pattern of shoreline foraging when first monitored on VP. This difference in the location of nightly activity for raccoons from VP and EL strongly suggests that they altered their foraging pattern in response to the breeding seabirds.

Unlike the results of this study, Urban (1970) found no evidence that raccoons on a managed waterfowl marsh shifted their movements or foraging activity in response to the arrival of breeding birds. This disparity is probably related to differences in the relative concentration of prey in space and time between a waterfowl marsh and a seabird colony. Urban (1970) noted that the home ranges of raccoons contained up to 15 pairs of waterfowl, whereas the home range of both collared animals on EL encompassed the entire colony of of Ancient Murrelets, approximately 1,215 breeding pairs.

In summary, the comparison of raccoons in the presence and absence of seabirds indicated no difference in home range size or time of activity, but did indicate a difference in the location of activity. At VP, an area devoid of seabirds, raccoons foraged along the shoreline and denned primarily <150 m inland. Nocturnal movement over these distances would, on a colony island, result in contact with breeding seabirds. Consistent with this observation, raccoons on EL maintained home ranges which encompassed the seabird colony, and were found active inland significantly more often than raccoons at VP.

CHAPTER 3: RACCOON PREDATION ON BURROW-NESTING SEABIRDS OF THE QCI

INTRODUCTION

Many studies have documented declines in seabird numbers following the introduction of predators, but relatively few have attempted to directly quantify alien predation while it is occurring (Norman 1971, Jones 1977, van Aarde 1980, Petersen 1982). In the absence of historic data documenting changes in colony size, area or breeding success, direct quantification is needed to predict whether and how quickly seabird numbers will decline following introduction of a predator. This chapter therefore describes and quantifies raccoon predation on burrow-nesting seabirds within a single breeding season to identify the probable consequences of prolonged raccoon-seabird contact.

Research was conducted within the Ancient Murrelet colony of EL, where several lines of evidence suggest that prior contact with raccoons has occurred. In 1971, the Limestone Islands were estimated to contain approximately 5,000 pairs of breeding seabirds (Summers 1974). In 1977, Campbell and Garrioch (1979) estimated the population at 15,000 pairs. By 1983, however, a detailed census of both islands indicated a breeding population of just over 1,600 pairs (Rodway et al. 1988). Although comparisons are confounded by differences in survey methods, Summers and Rodway (1988) interpreted the pronounced difference in population estimates as evidence of a decline, and suspected raccoon predation as the cause.

This conclusion was supported in part by burrow occupancy data. In 1983, burrow occupancy on WL was only 20%, significantly lower than the 61% occupancy rate recorded for EL and the median occupancy rate of 63% calculated for other Ancient Murrelet colonies of the QCI (Rodway et al. 1988). The only other Ancient Murrelet colony with a similarly low burrow occupancy was Langara Island (26%), where introduced rats were suspected of causing extensive seabird losses (Bertram 1989).

Further evidence implicating raccoons came from sign of predation. In 1983, high levels of predation were recorded on the Limestone Islands (Rodway et al. 1988). In addition, several sites of digging, the head of one Ancient Murrelet, and a raccoon scat were found on WL. In 1989, a radio-collared raccoon moved onto the Limestone Islands (Chapter 2), at which time distinctive evidence of predation was found in the colony, e.g. dug burrows, broken eggs and decapitated seabird carcasses. Such evidence of predation was not noted in extensive surveys of colonies throughout the QCI (Rodway et al. 1988), nor in 4 years of detailed research on Ancient Murrelets on Reef Island, 10 km offshore of the Limestone Islands (Gaston 1992).

The occurrence of this distinctive predation, concurrent with the presence of at least one raccoon, clearly implicated the raccoon as the predator. Data collected were not sufficient, however, to conclusively tie the raccoon to the observed predation. More important, they were not adequate to quantify the level of predation. An intensive study of predation on seabirds was therefore undertaken in 1991, with the following objectives:

a) to document the abundance of raccoons on the Limestone Islands throughout the breeding season, and to relate the level of predation observed to the number of raccoons present (spotlight surveys).

b) to describe raccoon predation on seabirds, both to quantify predation within the colony, and to aid in identifying the presence of raccoons on other colonies (site investigations).

c) to measure the level of raccoon predation on seabirds, and evaluate their potential impact on seabird colonies in the QCI (predation transects and carcass monitoring).

METHODS

Presence of raccoons

The minimum number of raccoons present on EL during the seabird breeding season was estimated by spotlight surveys. These were conducted approximately every other night, according to the methods described in Chapter 2.

Description of Predation

Site investigations

Site investigations were conducted to determine the frequency with which locations of active raccoons were associated with correspondingly recent evidence of predation, and to describe such predation. Raccoons were located at night using telemetry and spotlighting, as described in Chapter 2. On the following day, a circular area (r=150 m) was searched, centred on the site where the raccoon was located. Any evidence of mammalian predation estimated to be less than a day old was recorded, e.g., diggings, broken eggs and seabird carcasses, and each site described in detail (see form, Appendix D).

Initially, site investigations were conducted at various times on the day following location of the raccoon. When it became apparent, in early May, that avian scavengers (e.g. crows and bald eagles) were removing and/or altering the nature of the predation remains in the pre-dawn hours, the timing of site investigations was changed to begin at approximately 0400 h, before avian scavengers were active.

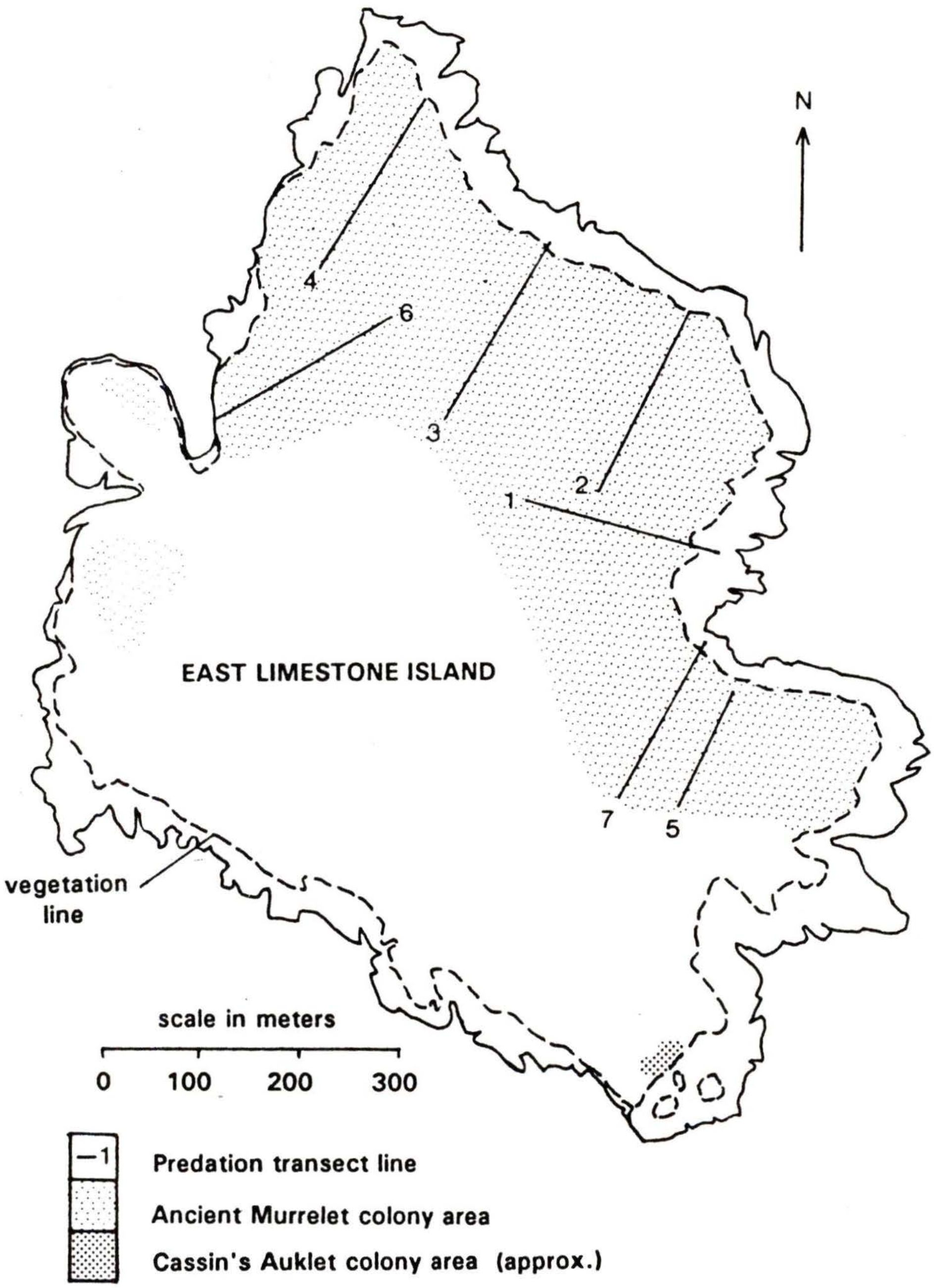
Level of Predation

Predation transect surveys were conducted to estimate the number of seabirds killed within the colony, and the proportion of those killed by raccoons. Seven predation transects were established on EL by the Laskeek Bay Conservation Society in 1990 (Fig. 17). Transects were oriented roughly perpendicular to the shoreline and extended across the colony, 120-200 m inland, following methods outlined by Rodway et al. (1988). Transects were surveyed in the early afternoon, every 3 days, throughout the breeding season. On each survey, two observers searched a 10 m strip on either side of the transect, recording the location of all signs of predation. Evidence of predation was flagged to ensure against double-counting. Using this method, an estimated 17% of the colony area was searched.

Four kinds of evidence of predation were recorded on the transects: diggings, broken eggs, chick and adult carcasses, and feather piles. Evidence of digging occurred in and around seabird burrows, and was counted according to the number of burrows either partially or completely excavated. A digging was not considered evidence of predation unless accompanied by other sign, such as eggs, chick remains, featherpiles, adult carcasses, or fresh blood. This is a conservative protocol, as some digging not accompanied by such sign may have resulted in mortalities.

Broken eggs fell within two categories: those which had hatched naturally and those which had been preyed upon. The former were separated from the latter by the presence of a thickened membrane, which develops immediately prior to hatching (A. Lawrence, pers. comm.). Predation on chicks was detected by the presence of downy grey feathers, or skeletal remains. Carcasses of adult seabirds were typically decapitated, but were sometimes "inverted", with the skin turned inside out and the spinal column protruding. Both kinds of adult carcass were considered to have originated from raccoon predation.

Figure 17. Map of East Limestone Island depicting location of Ancient Murrelet and Cassin's Auklet colonies, and predation transects.


N
EAST LIMESTONE ISLAND
1
2
3
4
5
6
7
vegetation line
scale in meters
0
100
200
300
—1 Predation transect line
Ancient Murrelet colony area
Cassin's Auklet colony area (approx.)

Feather piles were defined as concentrations of feathers considered sufficient to represent a single bird. Plucked feathers covering an area of about 1-2 m^2 were recorded as one feather pile, but a few feathers scattered over a larger area were not. Feather piles were not necessarily the result of raccoon predation.

Carcass monitoring

When avian scavengers were observed converting some adult seabird carcasses into feather piles, it became obvious that conducting predation transect surveys in the afternoon biased results against detecting raccoon predation. Accordingly, carcass monitoring was initiated to develop a correction factor for estimating what proportion of carcasses created by raccoons were being converted to feather piles, or removed from the colony, and how quickly.

Initially carcasses which originated from raccoon predation were monitored where found, on a daily basis. The condition of the carcass was noted, especially whether it had been altered to a form no longer recognizable as originating from raccoon predation (i.e. a feather pile). When it was determined that scavenging usually occurred the first day, continuous monitoring was instituted. Carcasses were collected when found, and either returned or placed in a new location in the pre-dawn hours. Observers then watched continuously from a hidden location for 5 h or until scavenging was complete, whichever occurred first. Any carcass not scavenged within 5 h was subsequently monitored daily. When possible, carcasses were marked with plastic wing and leg bands, and/or fluorescent powder to facilitate the identification of scavenged prey remains removed from the monitoring site. The location and fate of marked remains were recorded opportunistically.

RESULTS

Field work began in late March 1991, near the beginning of the Ancient Murrelet breeding season, and continued until mid-June, by which time most breeding birds and their chicks had left the colony (Gaston 1992). Field work was concentrated on EL because WL had only a small number of birds (Rodway et al. 1988).

Presence of raccoons

Nineteen raccoon sightings were made on 35 spotlight surveys of EL, conducted from April to June 1991. On 20 surveys, no raccoons were seen. On 12 surveys, only one raccoon was seen; on 2 surveys, 2 were seen; and on one survey, 3 raccoons were seen. Therefore at least 3 different raccoons were present on EL within the study period.

One was the radio-collared male, M35, documented moving onto the island in 1989. The transmitter on his radio-collar had since expired, but the collar was useful for visual identification. This male was sighted 9 times throughout the study period, including one sighting on WL. Thus as in 1990 (Chapter 2), his home range encompassed both islands in the spring of 1991.

The second raccoon present was an adult female (F05), radio-collared on EL at the outset of the 1991 seabird breeding season and monitored for its duration, March to June. This female is assumed to be the same female first sighted on EL the previous fall, with two kits; she was rearing another pair of offspring in 1991. If the timing of breeding is comparable to that observed in Minnesota (Schneider et al. 1971), these kits would not have begun nightly movements with her until after most seabirds had departed. F05 was consistently located on EL, throughout the duration of the seabird breeding season (Chapter 2).

The remaining raccoons sighted were uncollared or unidentified. As 2 uncollared raccoons were observed together on WL, and the greatest number of unidentified animals seen on any one night was 2, it is possible that these were the yearling offspring of F05. If so, their occupation of EL was intermittent during the period of study, and the number of raccoons on EL varied from 1-4 throughout the seabird breeding season.

Description of Predation

Site investigations

Four of the 11 sightings of M35, and 14 of 24 night locations for F05 were followed up with site investigations. Results from 15 of these 18 site investigations were usable. Three were excluded because telemetry bearings did not intersect, although they did indicate the general area where the raccoon was active.

On 11 of 15 site investigations recent evidence of raccoon predation on seabirds was present, including 4 cases of multiple predation (Table 10). On May 10, 10 Ancient Murrelet carcasses were found within 30-60 m of the previous night's sighting of M35. Strong signals were also obtained for F05 in this area, but no bearings were taken, hence at least two animals may have participated in producing these carcasses. On June 6, 6

Table 10. Evidence of predation found during site investigations, April 8 to June 13 1991, on East Limestone Island.

SITE INVESTIGATION NO.	DATE	TIME	ANIMAL	PREDATION SIGN FOUND	DISTANCE FROM ANIMAL LOC. (m)
1	April 8	12:30	F05	C	0
				D+2E	25
2	April 14	(PM)	F05	none	---
3	April 27	08:20	F05	none	---
4	April 29	(AM)	F05	none	---
5	May 10	06:00	M35	C	45
				2C+D	60
				C	50
				C	45
				C	30
				C	35
				2C+D	45
				C	45
6	May 15	06:30	F05	D+1E+F	95
7	May 19	05:30	M35	D+2E+F	30
8	May 22	13:00	M35	none	---
9	June 3	04:50	F05	C	30
10	June 5	16:30	F05	F/blood	15
11	June 5	17:30	F05	F/blood	80
				F/blood	35
12	June 6	04:45	F05	2C	145
				C	140
				C	95
				C	85
				C	165
13	June 7	05:00	F05	C	65
				C	20
14	June 8	04:40	F05	3C	70
				C	80
				C	80
				C	65
15	June 13	02:30	M35	C	25

C=carcass or pieces of carcass
D=digging
E=egg
F=feather pile

carcasses were located 85-165 m from the radio-location obtained for F05, 1.5 h earlier. The next day, 2 carcasses were found 20 m and 65 m from the previous night's sighting of F05, and on June 8, 6 carcasses were found 65-80 m from the radio-location obtained for F05, 2 h previously. The most definitive evidence of the role of raccoons in producing these carcasses came on June 13, with the discovery of a decapitated Pigeon Guillemot, 25 m from where M35 was observed pulling a bird from a rock crevice 2 h earlier.

Remaining sign recorded on site investigations consisted of diggings with eggs and/or feather piles, sometimes stained with blood. In such cases, adult birds were probably scavenged prior to their detection. Cases of multiple predation were found only when site investigations were initiated in the pre-dawn hours; no carcasses were detected during site investigations conducted later in the day, as would be expected with scavenging occurring in the early morning hours.

Level of predation

A total of 21 predation transect surveys were conducted between April 9 and June 8 1991. These yielded 106 records of predation (Table 11), representing the loss of 83 adult and subadult birds (breeders and non-breeders) and 32 juvenile birds (eggs and chicks). Extrapolation of these values to the entire colony suggests that 488 adult birds, and 188 eggs or chicks, were preyed upon within the 60 day sampling period. The number of cases of predation recorded per 3-day sampling period ranged from 2 to 10 (X +/- S.D. = 5 +/- 2). There was no obvious trend in the number of cases recorded over time, nor in the occurrence of different kinds of remains relative to the breeding chronology of the seabirds (Fig. 18).

The number of cases of predation within different parts of the colony varied. Predation transects 5-7 contained the greatest number of signs of predation, transect 1 the fewest (Table 12). There was no obvious association between areas of human activity and the level of predation; the field camp was situated between transects 1 and 7, which contained the lowest and highest numbers of predations per metre, respectively. In addition, Gaston et al. (1989) detected no differences in burrow density within the colony which would account for different levels of predation. Transects with the most cases of predation were located in the steepest parts of the colony. Possibly EL raccoons, like those of VP, denned in this steep habitat, and thus were more frequently active in this vicinity.

Table 11. Evidence of predation on seabirds found on East Limestone Island along transects, April 9 to June 8 1991.

EVIDENCE OF PREDATION	NO. OF CASES	*NO. OF ADULT AND SUBADULT BIRDS*	*NO. OF EGGS OR CHICKS*	*NO. OF DIGGINGS*
Digging plus:				
1 egg	6		*6*	*6*
2 eggs	2		*4*	*2*
feather pile + 1 chick	2	*2*	*2*	*2*
feather pile + 1 egg	1	*1*	*1*	*1*
feather pile + 2 eggs	1	*1*	*2*	*1*
1 egg	13		*13*	
2 eggs	2		*4*	
feather pile	73	*73*		
carcass	6	*6*		
TOTAL PREDATION RECORDS	106	*83*	*32*	*12*

Figure 18. Number of predation remains found on predation transects from April 9 to June 8, 1991 according to the following categories: feather piles, carcasses, dead chicks and eggs.

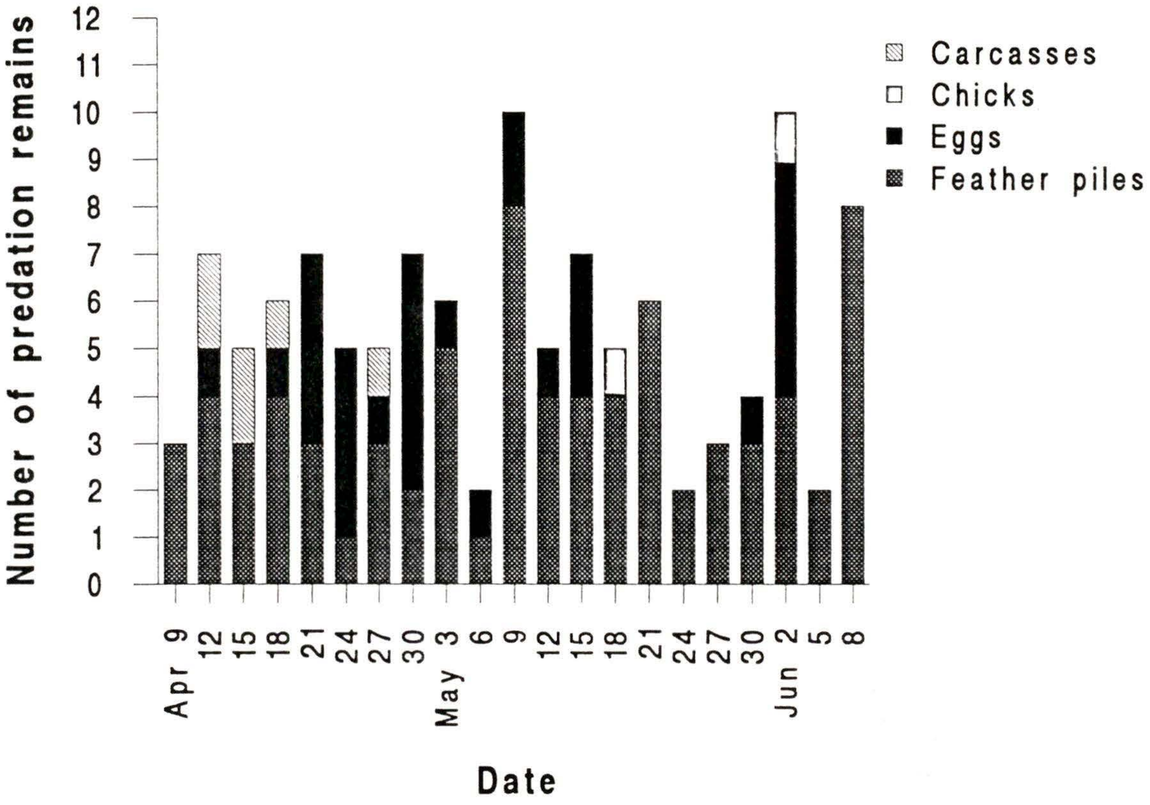

Number of predation remains
12
11
10
9
8
7
6
5
4
3
2
1
0
Apr 9
12
15
18
21
24
27
30
May 3
6
9
12
15
18
21
24
27
30
Jun 2
5
8
Date
Carcasses
Chicks
Eggs
Feather piles

Table 12. Number of cases of predation recorded for all predation transects, April 9 to June 8 1991.

PREDATION TRANSECT	LENGTH (m)	NUMBER OF CASES OF PREDATION	CASES OF PREDATION per metre	per hectare*
1	200	4	0.02	10
2	200	14	0.07	35
3	200	10	0.05	25
4	190	10	0.05	25
5	120	16	0.13	67
6	200	25	0.12	63
7	180	27	0.15	75

* calculated on basis of 20m survey width of predation transect

Twenty diggings were recorded on the transects, which varied in size and location. Digging sometimes began at the mouth of the burrow, and extended the full length to the nest cup (i.e. up to 1 m). In one case, a 5 kg rock was rolled away to provide access to the burrow. Typically, several small diggings (<20 cm) were located in and around the mouth of the burrow, suggesting that raccoons tried in several spots to locate the nest cup directly. Of the 20 diggings along transects, 12 were accompanied by egg(s) or chick(s), and 4 of these by feather piles. Thus most diggings along transects resulted in the failure of a nesting attempt, and 20% or more entailed the loss of at least one adult. Because raccoons were apparently "successful" on at least 60% of transect diggings, and burrow occupancy is only 40% for this colony (Gaston et al. 1989), raccoons may be selecting occupied burrows.

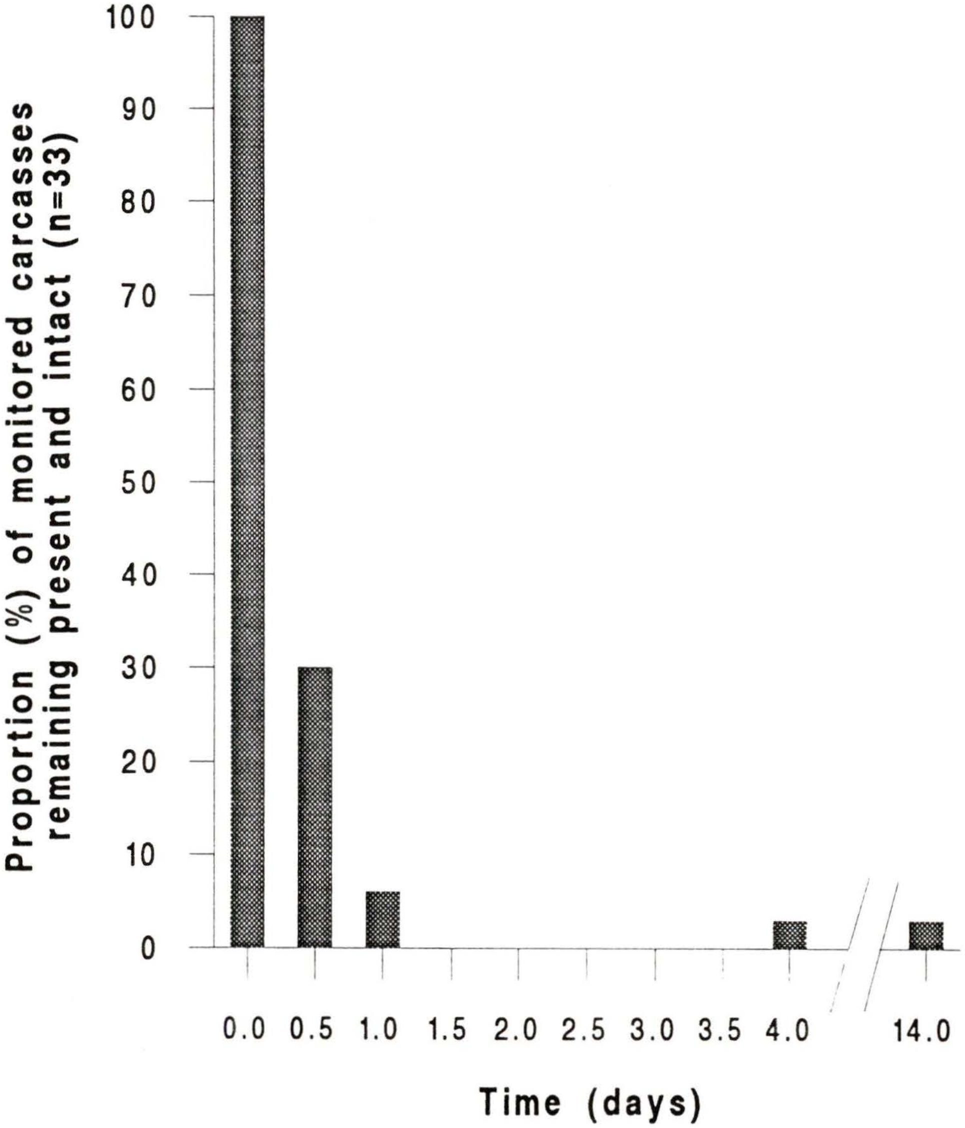
Thirty broken eggs were found on transects, between April 12 and June 2 (Fig. 18), both in association with diggings, and alone on the forest floor. Egg remains were usually half-shells, broken around the wide axis. One egg found late in the season (May 30) contained an uneaten chick embryo. Predation on chicks was documented on only two occasions, both cases in the second half of the season, and accompanied by a digging and adult feather pile. The low number of chicks preyed upon likely reflects their low availability, because they are present in their burrows only two days prior to departing at night for the sea.

Carcasses were the least abundant evidence of predation found on transects. Only six carcasses were found, all in the first half of the breeding season. If extrapolated to the entire colony area, this indicates a total loss to raccoon predation of 35 seabirds. Such an extrapolation severely underestimates the number of seabirds killed by raccoons, however, because it fails to take into account the loss of carcasses through scavenging, and their conversion to feather piles (see next section). Feather piles were the most abundant evidence of predation found on the transects, accounting for 93% of adult bird remains.

Carcass monitoring

Thirty-three carcasses were monitored in 13 carcass monitoring sessions. Of these, 31 were scavenged within the first day (Fig. 19), measured from dawn of the day on which a fresh carcass(es) was discovered, or placed on the forest floor for observation. Twenty-three (70%) of carcasses scavenged on the first day were either removed or converted to feather piles by noon.

Figure 19. Rate of conversion and/or removal of monitored seabird carcasses by avian scavengers (T=0 at dawn of the day on which the fresh carcass is present on the forest floor).


Proportion (%) of monitored carcasses remaining present and intact (n=33)
100
90
80
70
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
14.0
Time (days)

Only 2 of 33 carcasses remained intact for >1 day. The first of these was partially scavenged by day 2, but did not disappear until day 4. This carcass was located under a dense cedar canopy. A second carcass persisted more than 2 weeks, at which time monitoring was discontinued. This carcass was situated within a dense patch of regenerating spruce, and this atypical location presumably limited its detectability. Thus, predation transect surveys, conducted in the early afternoon of every third day, had a very low probability of yielding any direct evidence of predation by raccoons on seabirds.

Carcasses were monitored singly, and in groups of up to 5. Because avian scavengers were frequently active in groups, the removal rates of individual carcasses located in groups were probably not independent. In 9 monitoring sessions involving 2 or more carcasses, all were detected within 12 h, and all within 4 h of one another.

Coded remains were found for 11 of 28 carcasses, marked in 6 carcass-monitoring sessions. Remains of one bird were found at the original carcass site, and others from 40-375 m away. Scavenged predation remains included feather piles, inverted carcasses, and leg bands; none were identifiable as originating from raccoon predation. Because no systematic searches were conducted for scavenged remains, the proportion removed from the colony is unknown.

Crows (*Corvus brachyrhynchos*), immature and adult Bald Eagles (*Haliaeetus leucocehpalus*), and Ravens (*Corvus corax*) were all observed scavenging seabird carcasses. Crows and eagles were seen most frequently, and were often present together and in groups of 2-4 birds. Bald Eagles were seldom observed to feed on carcasses on the ground, but instead perched on snags to consume them. They dispersed feathers widely in doing this, and such widely scattered feathers could easily have been overlooked on predation transects. Crows were seen to "invert" carcasses while scavenging. Numerous such inverted carcasses were found concentrated within a ravine outside the colony boundary, hence at least some carcasses produced by raccoons were removed from the colony.

Results of carcass monitoring indicate that accurate estimation of raccoon predation hinges on determining the proportion of feather piles found within colony boundaries which originated as carcasses. Carcass monitoring indicated that almost all carcasses present on the forest floor at dawn were scavenged within one day (94%), the majority prior to noon (70%). Thus the number of carcasses found by midday of every third day, the time of predation transect surveys, can be described as a proportion of those remaining from each intervening day (Table 13). The following calculation used the data from carcass monitoring to estimate the number of carcasses produced in the colony over the period of study, yielding the observed 6 carcasses on the predation transects.Based on the disappearance rates of monitored carcasses, an estimated 43 carcasses were originally present on predation transects, to produce the 6 carcasses found on survey days. If this value is extrapolated to represent the entire colony area, 252 carcasses were produced within the colony between April 9 and June 8 1991.

This estimate represents 52% of the total number of adult seabirds known to have been killed within the colony. Given an estimate of 4 raccoons present on the colony during the breeding season, predation levels averaged 63 seabirds/raccoon, or 1 seabird/raccoon/night. The number of raccoon present varied over the course of the season, and so some raccoons were probably responsible for more predation than others. This is consistent with observations of multiple predation documented during site investigations.

Table 13: Proportion of seabird carcasses produced over three nights, which remain intact at the time of predation transect surveys (D_3). Proportions based on the results of carcass monitoring (n=33).

Time (Night/Day)	Number of carcasses produced	Number of carcasses remaining (midday)
N_1	C_1	
D_1		$0.30C_1$
N_2	C_2	
D_2		$0.06C_1 + 0.30C_2$
N_3	C_3	
D_3		$0.06C_1 + 0.06C_2 + 0.30C_3$

Assuming that predation is equal each night,

$$C_1 = C_2 = C_3 = C_{night}$$

then the number of carcasses found per survey, F, is

$$F = (0.06C_1 + 0.06C_2 + 0.30C_3)$$

$$F = (0.06 + 0.06 + 0.30)C_{night}$$

$$F = 0.42C_{night}$$

and the number of carcasses found throughout the season, FS, is

$$FS = 0.42C_{night} \times \text{no. survey days.}$$

As six carcasses were found in 21 predation transect surveys,

$$6 = 0.42C_{night} \times 21$$

and $C_{night} = 0.68$

The number of carcasses produced per 3-day survey period, C_s,

$$= 3(C_{night}) = 2.04$$

and the number of carcasses produced throughout the period of study (63 days),

$$= 21(C_s) = 43$$

DISCUSSION

Description of Predation

The occurrence of burrow-diggings, headless carcasses, and broken eggs on EL following the initial arrival of raccoon M35 provided circumstantial evidence that raccoons produced such sign of predation. Site investigations provide further evidence for the association between raccoons and this characteristic sign. Although the occurrence of fresh remains near the location documented for an active raccoon does not prove the raccoon responsible, frequent association between the two (11 of 15 site investigations) clearly implicates raccoons as the source. The direct observation of raccoon M35 killing a Pigeon Guillemot, and the subsequent discovery of a headless carcass at that site, essentially confirms their responsibility for this kind of predation.

The evidence of predation found in this study - digging, broken eggs and headless carcasses - is similar to that reported for raccoon predation on various other species. Raccoons commonly dig to gain access to the nest site or, in the case of mammalian prey, the den site. Reardon (1951) reported that raccoons "pawed at" 80% of duck nests preyed upon, partially or completely destroying their foundation. Raccoons excavate muskrat lodges to feed on the kits (see photo, Wilson 1953), and frequently dig up nests of alligators (Fleming et al. 1978, Joanen 1970) and various species of turtle (Stuewer 1943, Wilhoft et al. 1979, Christiansen and Gallaway 1984, Hopkins et al. 1978, Franz 1986, Davis and Whiting 1977, Christens and Bider 1987, Burger 1977, Stancyk et al. 1980).

Because fewer than half of the colony's burrows were occupied (Gaston et al. 1989), and yet most diggings were successful, raccoons were presumably using some cues to select occupied burrows. Such cues may have included the arrival of the foraging parent, and vocalizations within the burrow by the incubating adult or breeding pair (Gaston 1992). Other cues reportedly used by raccoons to detect buried nests of sea turtles include scent and soil disturbance (Stancyk et al. 1980).

Ease of excavation may have influenced the effort expended by the raccoon, as several diggings were sometimes present in the vicinity of the mouth of the burrow, but seldom exceeded 20 cm in depth, and sometimes ended where roots hindered excavation. Despite this observation, burrow characteristics are not likely adequate to protect most breeding birds. Rodway et al. (1988) found that of a sample of 40 burrows, 24% were on open ground, or adjacent to stumps, logs and dead roots, 38% were at the base of trees or within live tree roots, and 38% were within rock crevices. The former, excavated by Ancient Murrelets using their feet and bill, are likely to be relatively easy for raccoons to dig up, particularly where high burrow density has "honey-combed" the forest floor. Rock crevices or burrows adjacent to live trees may be more protected, but this depends upon the length and shape of the burrow. The Pigeon Guillemot described above was seen being pulled from a rock crevice, possibly its burrow.

Predation on eggs is typical of raccoons. Egg remains found at predation sites were usually half shells, frequently found away from areas of digging. Rarely, Ancient Murrelets will lay an egg upon landing in the colony (Gaston 1992), and raccoons may scavenge these solitary and exposed eggs. Most eggs found away from any other evidence of predation were probably excavated, however. Reardon (1951) found that duck eggs preyed upon by raccoon were sometimes transported up to 10 m away from the nest, to prominent rocks or to nearby water. Avian scavengers may also remove egg shells from the original predation site.

The most frequently encountered evidence of predation found in site investigations was the presence of headless carcasses, with little or nothing eaten. Up to ten such carcasses were found within the search radius surrounding the night location of one raccoon, consistent with the definition by Kruuk (1972) of surplus killing: "the killing of more prey than can be readily eaten by a predator, its offspring or members of its social group". Surplus killing has been reported for numerous carnivores, including mink, *Mustela vison* (Boggess 1983, Horstman and Gunson 1983), weasel, *Mustela* sp. (Henderson 1983, Horstman and Gunson 1983), fisher, *Martes pennanti* (Powell 1982), coyote, *Canis latrans* (Wade and Bowns 1982), cougar, *Felis concolor* (Wade and Bowns 1982), black bear, *Ursus americanus* (Boddicker 1983), red fox, *Vulpes fulva* (Kruuk 1972), and others.

Surplus killing usually occurs when a predator is placed in a situation where prey are abundant and easily obtained. Seabird colonies epitomize such a situation; thus, it is not surprising that surplus killing of seabirds has been recorded for several introduced predators. Kruuk (1972) observed that of 1449 gulls found killed by foxes over a three-year period, 97% were left uneaten. In a study of predation on tern colonies, Austin (1948) reported that the daily kill of a single rat (*R. norvegicus*) ranged from 3-20 birds, "with but a few mouthfuls eaten from one or two of the victims." And Petersen (1982) observed the surplus killing, by red foxes, of up to 100 adult Glaucous-winged Gulls and several hundred adult Tufted Puffins on an Alaskan colony island.

Ancient Murrelets are vulnerable to surplus killing at various stages within the breeding season. In the pre-laying period, groups of birds are active in the colony beginning 2-3 hours after dusk, vocalizing, prospecting and digging burrows, and fighting on the forest floor (Gaston 1992). This is followed by a period of reduced activity within the colony, with breeding birds incubating eggs for shifts averaging 3 days in length. Ancient Murrelets continue to be vulnerable during this period, as evidenced by the loss of several pairs of incubating birds at their burrows. Predation on breeding pairs can occur only during the change-over in incubation duties between the two birds, and their vulnerability at this time may be increased by the burst of vocalization with which members of the breeding pair greet each other (Gaston 1992). By mid-May, non-breeding birds begin intensive courtship activity in the colony. At this time, non-breeders may be found crouched near or immediately inside burrows, vocalizing and displaying (Gaston 1992). As in the pre-laying period, large numbers of birds are active on the forest floor, producing the abundant and easily obtainable prey characteristic of most surplus killing incidents (Kruuk 1972).

Level of Predation

The loss of adult birds recorded in this study is more significant than the loss of juveniles, both because of the greater number taken, and because the life history strategy of seabirds renders them most vulnerable to losses in the adult population (Moors and Atkinson 1984). Seabirds are long-lived and have relatively low reproductive rates, features which permit them to sustain periodic reproductive failure without being extirpated (Furness and Monaghan 1988). Seabirds also attain reproductive maturity relatively late in life, however, and normally suffer low adult mortality, conditions which contribute to their rapid decline in the face of heavy losses in the breeding population.

Gaston (1992) reports an average breeding success of 1.5 chicks per breeding pair of Ancient Murrelets. Thus a colony of 1,215 pairs would produce an estimated 1,800 chicks annually. The loss of 188 eggs or chicks therefore represents about 10% of production in 1991. This is likely to be an underestimate, for two reasons. First, the entire egg may sometimes have been eaten, leaving no evidence of predation. The lack of eggshell in EL scats (Chapter 1), and observations of other researchers suggest that only the contents are typically eaten (Reardon 1951, Greenwood 1979), but this varies individually (Johnson 1970). Second, where one egg was preyed upon, the second egg of the clutch was probably not successfully incubated, whether due to predation, damage to the burrow, nest desertion, or the possible loss of one or more of the breeding pair.

Interpretation of adult losses is confounded by the lack of information on the reproductive status of birds that were killed. The examination of brood patches and measurement of wing lengths, for carcasses collected both on and off the predation transects indicated that both breeding and non-breeding birds were being killed (A. J. Gaston pers. comm.). However, the proportion of each taken by raccoons is unknown. Given the timing of breeding activities, it is possible that breeding birds are preyed upon more heavily in the first half of the season, and non-breeders more heavily in the latter half. Non-breeders are less experienced on land, unfamiliar with the colony, and engaged in different activities than breeders, all of which may render them more vulnerable to predation.

The loss of 252 birds therefore represents 10% or less of the breeding population (1,215 +/- 250 S.E.; Gaston et al. 1989), and an unknown proportion of the non-breeding population. The estimate of 252 seabirds killed by raccoons is likely conservative, because it is based only on the presence and disappearance rate of headless carcasses. Although site investigations led primarily to carcasses, raccoon predation may sometimes result in a feather pile (Kilham 1971, Greenwood 1981). The presence of ribs, feet, portions of the sternum, and varying quantities of feather in raccoon scats from EL (Chapter 1) confirms that in a least some cases, raccoons ate a considerable amount of the carcass.

An assumption made in calculating the above estimate of predation is that the level of nightly predation by raccoons was equal throughout the period of study. The extent to which predation levels varied is in fact unknown. Evidence of surplus killing indicates that raccoons sometimes killed more than the estimated average of 1.0 seabird/night. Conversely, spotlight records indicate that not all raccoons were present on EL throughout the study period, which may have reduced predation on some nights. As transect results indicated that overall predation levels did not differ markedly throughout the period of study, the assumption of relatively constant predation levels is supported.

A second assumption made in estimating the level of predation by raccoons on seabirds is that carcass monitoring results are indicative of the fate of all carcasses produced by raccoons. Among the factors which could contribute to a higher rate of disappearance for monitored carcasses are a) observer effect, b) bias in the habitats in which monitoring took place, and c) lack of independence of observations.

Observer effect could occur if avian scavengers associated the presence of people with the presence of carcasses, and therefore detected them more readily. This is unlikely, however, because workers usually conducted site investigations and began monitoring activity well before dawn, and noted the arrival of birds >30 min later. Bias in the selection of carcass monitoring locales, for example in favour of open habitats with good visibility, could influence the rate of carcass detection. This is an unlikely source of error, as observers monitored carcasses where they were found, or in habitats with similar cover. Furthermore, most of the understory is relatively sparse, due to browsing by black-tailed deer.

Lack of independence in the detection rate for carcasses present in groups has already been mentioned. Because avian scavengers were frequently in groups of 2-4, the discovery of one carcass probably influenced the speed with which nearby carcasses were found. Placing some carcasses out in groups for monitoring could therefore contribute to a bias in their rate of detection and removal. Site investigations indicated, however, that surplus killing produced groups of carcasses naturally within the colony. Monitoring of groups of carcasses as well as individual carcasses therefore simulated the situation in the colony, and should not have introduced significant bias.

The estimate of 252 seabirds killed by raccoons represents just over half (52%) of all seabirds known to have been killed within the colony. Data collected on EL in 1992, the year following this study, provide further evidence that this value underestimates the extent of predation by raccoons. In the fall and winter of 1991, upon completion of this predation study, three raccoons were removed from EL by trapping and hunting: M35, F05 and an uncollared animal. Seabird losses recorded on predation transects during the subsequent seabird breeding season decreased by 85%, from 115 to 17 (Gaston and Lawrence 1993). Thus although the estimate of 252 seabirds indicates that raccoons effect heavy predation, it nonetheless represents only a minimum.

The high estimate of raccoon predation obtained in this study is consistent with those obtained for introduced predators on other colony islands. Based on the relationship between scat contents and dietary requirements, Jones (1977) estimated that 375 feral cats on MacQuarie Island (Australia) consumed 58,000 petrels and prions per year. As seabirds were present on MacQuarie for 9 months of the year, this corresponds to roughly 155 seabirds per cat, or 0.57 seabirds/cat/day. Using a similar approach, Van Aarde (1980) estimated that 2,100 feral cats on Marion Island (South Africa) killed 450,000 seabirds per year. With a year-round seabird population, this corresponds to an average of 213 seabirds per cat, or 0.58 seabirds/cat/day.

Petersen (1982) found that two foxes with temporary access to Shaiak Island, Alaska, killed 13 (8.3%) of 156 Tufted Puffins breeding within ten 25-m^2 plots, and contributed to the almost complete breeding failure of five of seven seabird species inhabiting the island. Although this colony was only slightly larger in area than that of East Limestone, it contained an estimated 156,000 seabirds, a much denser prey population. Tufted Puffins, the only burrow nesters present on the island, lost fewer eggs and chicks to the foxes than did surface nesting species, but adults appeared to sustain the greatest losses.

Ancient Murrelets are unlike most other seabird species in rearing two precocial young, which travel to sea within two days of hatching (Gaston 1992). Other burrow-nesters on the QCI feed their young for several weeks within the burrow before departing the colony, a strategy which may increase their exposure and hence vulnerability to predation. On Langara Island, which has been subject to rat predation for almost a century, the Ancient Murrelet is the only one of five burrow-nesters still present (Rodway et al. 1990). Therefore, we can expect raccoon predation on other burrow-nesters to match or exceed that observed for Ancient Murrelets in this study.

Summary

The limited historical records for the Limestone Islands indicate that an unexplained decline in seabird numbers has occurred over the past 10-20 years (Campbell and Garrioch 1979, Summers 1974, Rodway et al. 1988, Gaston et al. 1989). Results of this study strongly suggest that raccoons have contributed to this decline. Raccoons were documented to prey on eggs, chicks, subadults and breeding adults, often killing more birds than were eaten.

The long-term outcome of raccoon predation on seabirds depends upon several factors not examined in this study. These include the ratio of breeding to non-breeding birds being killed, the number of non-breeders investigating the colony annually, the influence of disturbance by predators on these prospecting birds, and the relationship between seabird losses resulting from predation by raccoons, and those resulting from other sources.

Given the magnitude of the documented predation, however, and its effect on all life history stages of the population, it is unlikely that losses in one category will be compensated by recruitment through another. Consequently, prolonged exposure to raccoon predation appears likely to produce the local extinction of breeding seabirds on EL.

CHAPTER 4. RACCOON DISTRIBUTION AND CONTACT WITH BURROW-NESTING SEABIRDS ON THE QCI

INTRODUCTION

Knowledge of the distribution of introduced predators, and factors which influence their range expansion, are of key importance in evaluating their potential threat to breeding seabirds. Previous chapters indicated that raccoons may be capable of surviving on many colony islands, and that they prey heavily on burrow-nesting seabirds when present (Chapters 1-3). For the seabird population of the QCI, the significance of these results must be qualified by the probability that raccoons will reach colony islands. If most colonies lie within distances that raccoons can swim, then raccoons may access them and cause severe losses. If most seabirds breed on inaccessible islands, then the overall impact of raccoons will be limited.

The key question is thus how the distribution of colony islands relates to the over-water distance raccoons can cross. By the mid-1980's, raccoons had reached at least 13 islands off the east coast of Moresby (Summers and Rodway 1988, Powell 1988), and in attaining this distribution had completed crossings of at least 720 m of open water. However, the relationship between island distance, colony size, and accessibility to raccoons had not been systematically assessed. The goals of this chapter are to identify those islands where raccoons and seabirds were in contact and, based on island size and offshore distance, determine which islands were most vulnerable to future access. This information is needed to rank islands and island complexes for monitoring and control efforts aimed at the conservation of seabird populations.

METHODS

Selection of Islands

To meet these goals, a sample of islands was surveyed over two summers, 1990 and 1991. The selection of islands was based on the presence of seabirds, the range of offshore distances, logistics and safety.

To determine which colony islands had raccoons, colony islands closest to source areas were selected. If several colonies close to source areas were devoid of raccoon sign (i.e. scats or sightings), more distant colonies were not necessarily searched. Emphasis was placed on surveying major colony islands, herein defined as colonies containing more than

25,000 breeding seabirds.

To document the over-water crossing distance traversed by raccoons, both colony and non-colony islands were selected over a range of crossing distances, from <10 m to >1.2 km. The crossing distance was defined as the minimum distance between an area known to have raccoons and a candidate island, as measured at low tide, and including intertidal rock(s) exposed only at low tide. Where several crossings along a chain of islands were required, the longest of these was taken. Distances were measured to the nearest millimetre from marine charts (from 1:36,600 to 1:73,026), and rounded to the nearest 5 m following conversion. Given the range in map scales used, and the inherent error in distance measurement, an error of approximately +/- 100 m is associated with these values.

Islands serving as "stepping stones" to colonies were also surveyed, to determine how far along such chains raccoons had travelled. The number of stepping stones providing access to a particular colony was determined according to the route demanding the shortest over-water crossings. Usually this was also the most direct route. Stepping stone islands were counted beginning from Moresby, Graham, or islands connected to them at low tide.

The final sample of islands was modified by logistics and safety concerns. Time constraints limited the number of islands which could be visited, and the sea conditions in different parts of the region influenced the distribution of surveyed islands. Whereas islands situated off the east coast of the archipelago could be reached with an inflatable boat, many located off the exposed west coast could not safely be surveyed this way. Consequently, survey effort was most intensive on the east side of the archipelago. Selected islands off the west coast were visited by boat or helicopter, but the time and cost associated with surveying more of this region limited the number of islands surveyed.

Survey Methods

Two main methods were used to detect raccoons: standardized, shoreline "latrine circuits" and "spotlight circuits" of the intertidal zone at night. Latrine circuits were intensive surveys of approximately 300 m of shoreline, in which all latrines and scats found within 10 m of the landward side of the forest margin were recorded. The exact distance of the circuits was estimated from start and end points identifiable on marine charts. Spotlight circuits were conducted from 30-50 m offshore by rowing or running an inflatable boat at low speed, while scanning the shoreline with a 750,000 candle-power spotlight. Raccoons were detected by the glow of their eyes, which could be distinguished from that of other mammals in the region (e.g. deer, otter) by their red colour and narrow spacing, and the speed with, and manner in, which the animal moved.

Specific survey locations, whether for latrine or spotlight circuits, were chosen to maximize the probability of detection. Observations made at Vertical Point (Chapter 3) indicated that sheltered low gradient shorelines were more heavily used by raccoons than were exposed bedrock shorelines. Accordingly, as much as possible, latrine or spotlight circuits were located on pocket beaches with mixed cobble-boulder substrate, or bays and channels with extensive exposure at low tide. Large islands were surveyed at >1 location, including the nearest point of access from adjacent shores, and potential points of departure to more distant islands.

For some islands which could not be surveyed using latrine or spotlight circuits, additional information was gathered through "spot checks" for scats, and scanning of the intertidal zone during daylight hours, at low tide. Spot checks were searches of those sites considered most likely to contain raccoon sign, such as knolls, stumps and logs along the shoreline, and were conducted where time and accessibility were limited. Daylight shoreline scans were conducted for several islands which could not be safely surveyed with the spotlight at night, due either to their distance from base camp or the presence of intertidal rocks. Positive results obtained with these methods were reported. However, due to the cursory nature of the searches, negative findings were not considered comparable to those obtained using the more intensive methods described above, and hence were excluded from further analysis and discussion.

RESULTS

Survey Results

In August of 1989 and 1990, a total of 71 islands adjacent to Graham and Moresby Islands were searched for sign of raccoons. On 10 of these islands, spot checks for scats or daylight shoreline scans yielded no sign, and these were excluded from the results for reasons described above.

Of the remaining 61 surveyed islands, 25 contained burrow-nesting seabirds and 36 did not. The 25 surveyed colonies represent 38% of all known, burrow-nesting colonies of the QCI, and contain an estimated 71% of the region's burrow-nesting population

(Rodway et al. 1988). Eighteen of 31 colonies located off the east coast were surveyed, representing 91% of the east coast seabird population; seven of 34 colonies off the west coast were surveyed, representing 61% of the west coast population. Ten of the 14 major colonies (>25,000 breeding birds) present in the QCI were surveyed.

Raccoons or signs of their presence were found on 35 of 61 surveyed islands (see Appendix E for raw data). Spotlight circuits encompassed roughly 1-5 km of shoreline, and revealed up to 21 raccoons on 13 islands. Raccoon scats were present on the remaining 22 islands. Latrine circuits contained from 0 to 643 scats, and when present, scats were typically either scarce (<5/circuit) or very abundant (>100/circuit).

Abundant scats occurred in locations known to have contained raccoons for several years, such as Burnaby, Harriet, Ross, Talunkwan, Louise, Moresby, and Swan Islands, and were assumed to indicate a resident population. Scats were scarce on several islands on which no raccoon sign was detected in seabird surveys of the mid-1980's, such as Alder, George and Instructor Islands (Summers and Rodway 1988, Powell 1988). This suggests that the scats on these islands may have come from a small number of recent arrivals. More detailed evaluation of the differences in latrine circuit values is confounded by differences in habitats and proportion of total shoreline sampled on different islands.

All islands known to have been visited by raccoons are listed in Table 14. Three islands which contained no sign when surveyed in this study are known to have been reached on the basis of prior or subsequent sightings: Kunghit (Summers and Rodway 1988), Skincuttle and Skedans (VandenBrink 1992). Access has also been documented for Haswell Island, not surveyed in this study (Summers and Rodway 1988). These four islands have been included in Table 14, for a total of 39 islands known to have been visited.

On 26 islands, latrine circuits and/or spotlight counts yielded no evidence of raccoons. These islands have been listed in Table 15 (minus the 3 surveyed islands included in Table 14, as described above). The negative survey result obtained for these islands does not necessarily indicate that raccoons were absent, but that no sign was found in standardized surveys.

Colony Islands Reached by Raccoons

A substantial fraction of the total number of seabirds in the QCI are already in contact

Table 14. Islands of the QCI archipelago known to have been visited by raccoons.

ISLAND	LAT (N)	LONG (W)	AREA (ha)	OVER-WATER CROSSING (m)	# OVER-WATER CROSSINGS	BURROW-NESTING POPULATION*
Colony Islands						
1. Alder	52°26'52"	131°19'10"	62	265	1	35,320
2. East Limestone	52°54'30"	131°36'45"	48	300	1	2,898
3. George(?)	52°21'00"	131°12'27"	45	640	6	35,000
4. Instructor(?)	53°01'23	132°19'14"	4	220	1	6,420
5. Kunghit[a]	52°06'00"	131°04'00"	12,987	720	1	23,023
6. Helgesen	53°01'44"	132°26'15"	56	185	1	56,360
7. Rock(?)	52°20'42"	131°14'10"	6	640	4	44,200
8. Saunders	52°01'45"	132°27'53"	61	75	1	100
9. Skedans[b]	52°57'25"	131°34'37"	41	950	2	2,400
10. Skincuttle[b]	52°20'52	131°13'25	16	640	5	15,000
11. West Limestone	52°54'41"	131°37'16"	11	300	1	212
Non-colony Islands						
1. Boulder	52°17'30"	131°17'42"	7	190	1	(E)
2. Burnaby	52°24'12"	131°19'12"	6,596	0	0	---
3. Centre	52°25'04"	131°23'37"	2	170	2	---
4. De la Beche	52°32'23"	131°37'29"	34	225	2	---
5. De la Beche-S	52°32'15"	131°38'10"	15	<40	1	---
6. Ellen	52°09'21"	131°05'34"	20	720	2	---
7. Harriet	52°18'14"	131°13'35"	7	225	1	---
8. Haswell[a]	52°51'47"	131°41'04"	15	205	1	---
9. Hutton	52°31'11"	131°31'54"	14	225	1	---
10. Huxley	52°26'58"	131°22'29"	631	415	2	---

Table 14 (cont.). Islands of the QCI archipelago known to have been visited by raccoons.

ISLAND	LAT (N)	LONG (W)	AREA (ha)	OVER-WATER CROSSING (m)	# OVER-WATER CROSSINGS	BURROW-NESTING POPULATION*
Non-colony Islands (cont.)						
11. Island Bay 1	52°21'21"	131°24'16"	3	75	1	---
12. Island Bay 2	52°21'26"	131°23'45"	4	75	1	---
13. Island Bay 6	52°22'15"	131°22'23"	1	75	1	---
14. Island Bay 9	52°22'29"	131°22'08"	3	150	1	---
15. Island Bay 10	52°22'31"	131°22'21"	1	150	2	---
16. Kat	52°23'11"	131°22'32"	64	190	1	---
17. Louise	52°57'16"	131°45'39"	27,192	<10	1	---
18. Marco	52°31'18"	131°30'23"	28	150	1	---
19. MW-unnamed	52°31'15"	131°30'58"	2	115	1	---
20. Ross	52°09'45"	131°07'02"	23	0	0	---
21. Sea Pigeon	52°17'08"	131°17'04"	7	190	1	(E)
22. Section	52°25'17"	131°22'16"	13	75	1	---
23. Sels	52°25'27"	131°24'44"	3	300	2	(E)
24. Shuttle	52°39'28"	131°41'45"	256	450	1	---
25. Swan	52°20'04"	131°17'48"	28	115	1-3	---
26. Talunkwan	52°50'00"	131°45'00"	4,423	150	1	---
27. Unnamed "CB"	52°17'28"	131°07'55"	6	75	1	---
28. Wanderer	52°25'14"	131°24'07"	93	150	1	---

*	from Rodway et al. (1988, 1990)
a	Summers and Rodway (1988)
b	vandenBrink (1992)
(?)	scat of questionable origin, raccoon suspected
E	colony extinct

Table 15. Islands of the QCI on which latrine and/or spotlight circuits yielded no evidence of access by raccoons.

ISLAND	LAT (N)	LONG (W)	AREA (ha)	OVER-WATER CROSSING (m)	# OVER-WATER CROSSINGS	BURROW-NESTING POPULATION
Colony Islands						
1. Anthony	52°05'47"	131°13'06"	214	720	4	98,432
2. Bischoff	52°34'44"	131°33'51"	86	715	5	100
3. Bolkus	52°19'26"	131°16'57"	82	750	3-4	22,220
4. Carswell	53°01'18"	132°25'12"	22	475	2	4,340
5. Charles	52°09'18"	131°03'39"	5	720	1	460
6. East Copper	52°21'27"	131°10'39"	41	640	8	30,680
7. Frederick	53°55'45"	133°10'30"	470	655	1	316,000
8. High	52°07'38"	131°00'35"	49	720	2	20
9. Hippa	53°32'03"	132°58'25"	500	655	1	152,440
10. Howay	52°23'24"	131°15'38"	31	900	1	1,120
11. Langtry	52°13'55"	131°00'18"	4	825	1	24,600
12. Lyell	52°40'33"	131°29'05"	17,452	715	4	21,400
13. Ramsay	52°33'39"	131°22'53"	1,637	1,015	9	62,200
14. Rankine	52°15'29"	131°03'33"	58	1,275	1	132,600
Non-colony Islands						
1. Green Rk.	52°17'32"	131°17'05"	<1	565	2	---
2. Bush Rk.	52°18'14"	131°16'34"	<1	75	3	---
3. Hoskins	52°32'26"	131°32'52"	4	675	1	---
4. Kat Rks.	52°23'35"	131°22'52"	<1	225	2-3	---
5. Koga	52°25'46"	131°22'44"	3	490	2	---
6. Marco Rk.	52°31'09"	131°29'30"	<1	150	2	---
7. Nest Its.	52°17'40"	131°07'27"	2	375	2-3	---
8. Pelican Rk.	52°20'40"	131°15'21"	<1	225	1	---
9. Sivart	52°32'15"	131°35'20"	9	715	2	---

with raccoons. Raccoons have reached at least 11 islands occupied by burrow-nesting seabird colonies, 17% of those present in the QCI (Rodway et al. 1988) (Table 14). The total number of burrow-nesting seabirds breeding on these 11 islands is estimated at approximately 221,000 (Rodway et al. 1988), which represents 14% of the the total population of burrow-nesters on the QCI. Included in these 11 colonies are 4 of the 14 major colonies present in the QCI: Alder, Rock, George and Helgesen Islands.

Features of raccoon distribution

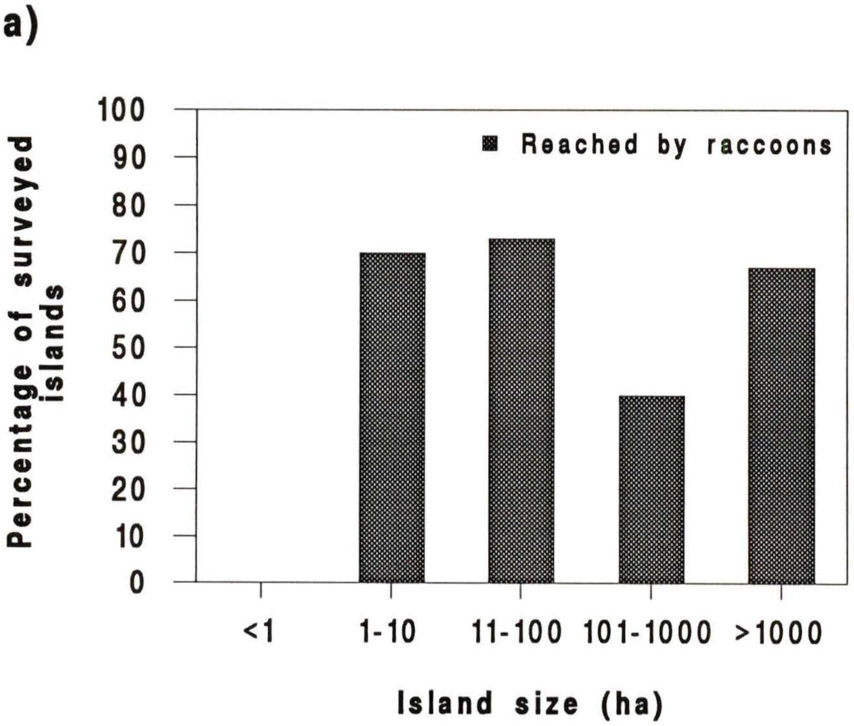
A distance effect was evident in the distribution of raccoons (Table 16). Raccoons have reached most (86%) surveyed islands requiring crossings of 400 m (+/- 100m) or less. Sign was present on an increasingly smaller percentage of surveyed islands situated further offshore, up to a maximum distance of 950 m (+/- 100m) (Skedans Islands). Most islands reached to date have required a maximum of 1-2 over-water crossings, which suggests that raccoons are still in the first stage of moving from the "mainland" onto adjacent islands.

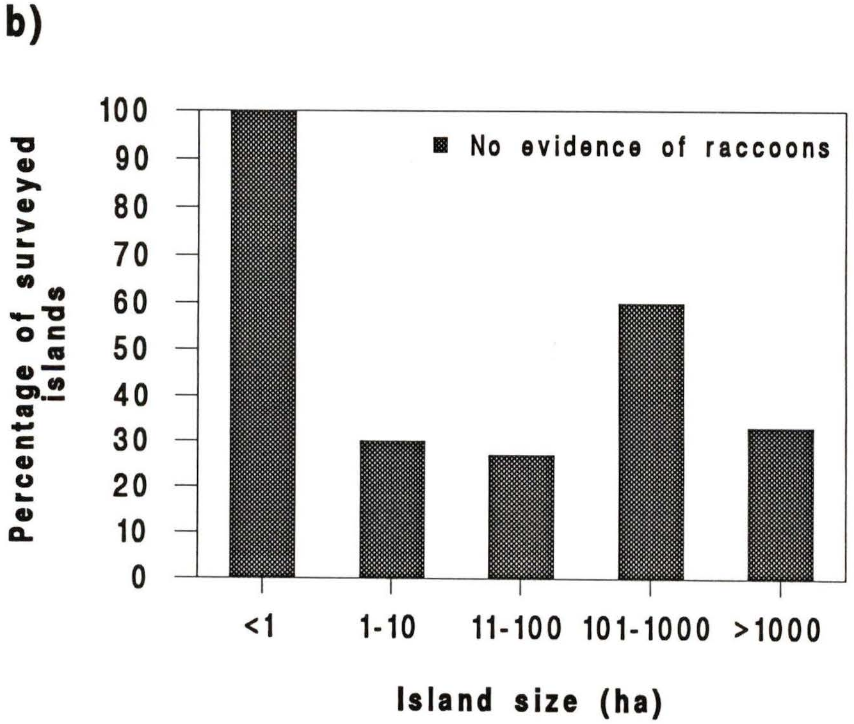
Raccoon sign was found on islands ranging in size from 1 to 27,192 ha, but was not found on any of 5 surveyed rocks <1 ha in size (Fig. 20). Four of these small rocks were accessible with over-water crossings of <225 m, a distance raccoons are clearly capable of swimming. The lack of sign on such rocks does not necessarily indicate that they have not been reached, but may instead indicate that raccoons visit such sites on a brief and infrequent basis, resulting in the accumulation of very little sign.

Table 16: The number and proportion of surveyed islands with raccoon sign, as a function of over-water crossing distance.

OVER-WATER CROSSING DISTANCE (m)	ISLANDS SURVEYED	ISLANDS WITH RACCOON SIGN	ISLANDS WITH RACCOON SIGN (%)
0-200	24	22	92
201-400	12	9	75
401-600	5	2	40
601-800	16	5	31
801-1000	3	1	33
1001-1200	1	0	0
1201-1400	1	0	0
TOTAL	62	39	63

Figure 20. Percentage of surveyed islands a) with and b) without evidence of raccoons, as a function of island size (n=5, 20, 26, 5, and 6 respectively, for categories of increasing island size).


a)
Percentage of surveyed islands
100
90
80
70
60
50
40
30
20
10
0
Reached by raccoons
<1
1-10
11-100
101-1000
>1000
Island size (ha)


b)
Percentage of surveyed islands
100
90
80
70
60
50
40
30
20
10
0
No evidence of raccoons
<1
1-10
11-100
101-1000
>1000
Island size (ha)

DISCUSSION

Evaluation of survey methods

For several reasons, this study indicates only the minimum extent of the raccoon's contact with breeding seabirds. First, most (62%) colony islands have not yet been surveyed, particularly those located off the west coast of the archipelago. Second, islands which were surveyed but were found to contain no sign may have been visited by raccoons in the past. Third, and perhaps most important, islands that had no sign may have contained raccoons at the time of the survey (a false negative).

Several factors influence our ability to detect raccoons or their sign, including the size of the island, the density of the raccoon population, and the survey method used. Because search effort was based on shoreline distance, the relative proportion of the shoreline surveyed was greater for small islands than for large ones. A 300 m latrine circuit encompasses 27% of the shoreline of a (theoretical) circular island of 10 ha, but only 2.7% of the shoreline of a 1,000 ha island. On large islands colonized only recently, considerable portions of the shoreline may not yet have been visited, and the selection of survey location takes on over-riding importance. For example, no raccoons were detected in several surveys of Kunghit Island, even though it was reached previously (Summers and Rodway 1988). Either the raccoons sighted previously had left or died, or survey effort was inadequate. Negative results on other large islands, such as Lyell, must therefore be interpreted with caution.

The probability of each survey method not detecting raccoons was not measured, but results from surveys conducted at VP and EL provide some basis for evaluating their accuracy. In March 1991, the entire perimeter of EL was searched for scats, at which time 3-4 raccoons were estimated to have been present for approximately one year. At that time, no 300m section of shoreline was found to be devoid of scats. In 20/35 subsequent spotlight counts, however, no raccoons were sighted (Chapter 3). Thus, for this 48 ha island, a latrine circuit would have detected the presence of a small and recent population, but spotlight counts were wrong over 50% of the time. As these spotlight counts were conducted during the seabird breeding season, when raccoons were more active inland, they may have been less accurate than had they been conducted during the winter, when seabirds are absent and intertidal foods again provide the dominant prey base (Chapter 2).

On VP, scats were abundant along the shoreline, and raccoons were detected on all but one of 43 spotlight circuits conducted in 1990. Furthermore, on the one occasion when no raccoons were seen, tourists and dogs likely displaced raccoons from the survey area. Thus, whereas both survey methods can detect a reasonably large raccoon population, a combination of methods is needed to detect raccoons where they are scarce.

The advantage of both latrine and spotlight circuits is that they can be standardized and repeated. Ability to conduct latrine circuits can be hindered, however, by rugged topography or dense vegetation along the shoreline, and spotlight circuits may vary in accuracy depending upon visibility (weather), shoreline topography, shoreline habitat, and tide height. Rybarczyk et al. (1980) also identified season, temperature and observer experience as factors influencing the number of raccoons seen in spotlight surveys. Thus, each method has an unmeasured and variable probability of error, depending upon features of the island, and specific conditions under which the survey was conducted.

A combination of latrine and spotlight counts seems the most useful means of detecting raccoons. Both methods were considered superior to spot checks and daylight shoreline scans because they were more intensive, permitted quantification of sign, and were best suited to the predominantly nocturnal behaviour of the species. Use of remote cameras and bait stations might also prove effective in surveying some islands, particularly those for which night work is difficult or unsafe. Ultimately, the value of surveys conducted in this region will depend upon their frequency and standardization. Results for any one island within any one year may be erroneous. Over time, however, such monitoring will provide information on the distribution of raccoons, and the pattern of range expansion.

Factors influencing raccoon distribution

Peltonen and Hanski (1991) stated that "comprehensive studies of island biogeography and metapopulation dynamics should include analyses of both the patterns of island occupancy and the processes that produce these patterns." This study is not a comprehensive examination of island biogeography, but rather an initial, and partial, "snapshot" of the raccoon's distribution on the QCI archipelago. Nonetheless, observed patterns of occurrence provide insights into some of the factors contributing to the raccoon's current distribution, and indicate the potential for extensive contact with burrow-nesting seabirds of the region.

A conceptual basis for examining the occurrence of species on islands was provided by the theory of island biogeography (MacArthur and Wilson 1967). However, island biogeography theory addresses only long-term processes of colonization and extinction on islands, relative to their size and distance offshore. On the QCI, where many islands are within the crossing range of raccoons, proximate factors related to the dispersal of individuals, such as age, sex and local population density must also be considered. This link between island biogeography theory and dispersal features of particular species has been recognized by Hanski (1986).

Biogeographic features influencing the accessibility of an island include its isolation, size, exposure, and the presence of stepping stones or other associated islands (clustering) (MacArthur and Wilson 1967). Demographic features potentially influencing dispersal onto islands include the density of the "source" population (Hanski 1986, Beer et al. 1954), and its effect on the age, sex and success of dispersing individuals. In the latter context, raccoons on the QCI represent essentially a metapopulation, connected by dispersal across a "sea" of less favourable habitat (Hanski and Gilpin 1991). What is not yet known on the basis of these surveys is the relative importance of these various biogeographic and demographic features.

Island isolation

Isolation has long been recognized as a key factor influencing the accessibility, and hence biotic composition of islands (Williamson 1981). In this study, as in most others, island isolation was quantified as offshore distance. Even this straight-forward measure, however, varies depending upon the choice of whether to calculate distances from the mainland, the nearest island, or the nearest occupied island (Lomolino 1986). Furthermore, a straight-line measure of the minimum crossing distance may underestimate the energy expended by an animal in reaching a particular island if currents or strong winds prevail, or if the animal travelled via a more indirect route.

In spite of the limitations associated with its measurement, a clear relationship emerged between the over-water crossing distance to an island, and the presence of raccoons or their sign. Raccoons were shown to be capable of reaching most islands within 400 m offshore, and were present on a gradually decreasing proportion of islands up to 950 m offshore. Such crossing distances exceed any reported in the literature for the species. Stuewer (1943) noted that raccoons frequently crossed the Kalamazoo River, a distance of roughly 50 m, and Frampton and Webb (1974) reported a lake crossing of 200 m by a translocated raccoon. Results of this study indicate that these distances represent only a fraction of the distance raccoons can cross.

It is unknown by what means raccoons accomplished the most distant crossings, whether by swimming or aided by chance events. Rafting and chance oceanographic events (Carlquist 1974, Clark and McInerney 1974, Desender et al. 1992) have played a major role in distributing species onto offshore islands. According to Lund (1978; cited in Moller 1983), rats can survive in water for up to three days, and Austin (1948) reported seeing rats on floating mats of debris, between the mainland of Massachusetts and adjacent colonies of breeding terns. However, rats have also been recorded as swimming up to 750 m (Lund 1978), and shrews and stoats distances of 1 km or more (Hanski 1986, Taylor and Tilly 1984). Thus, similar movements for a medium-sized, water-associated mammal such as the raccoon are not inconceivable.

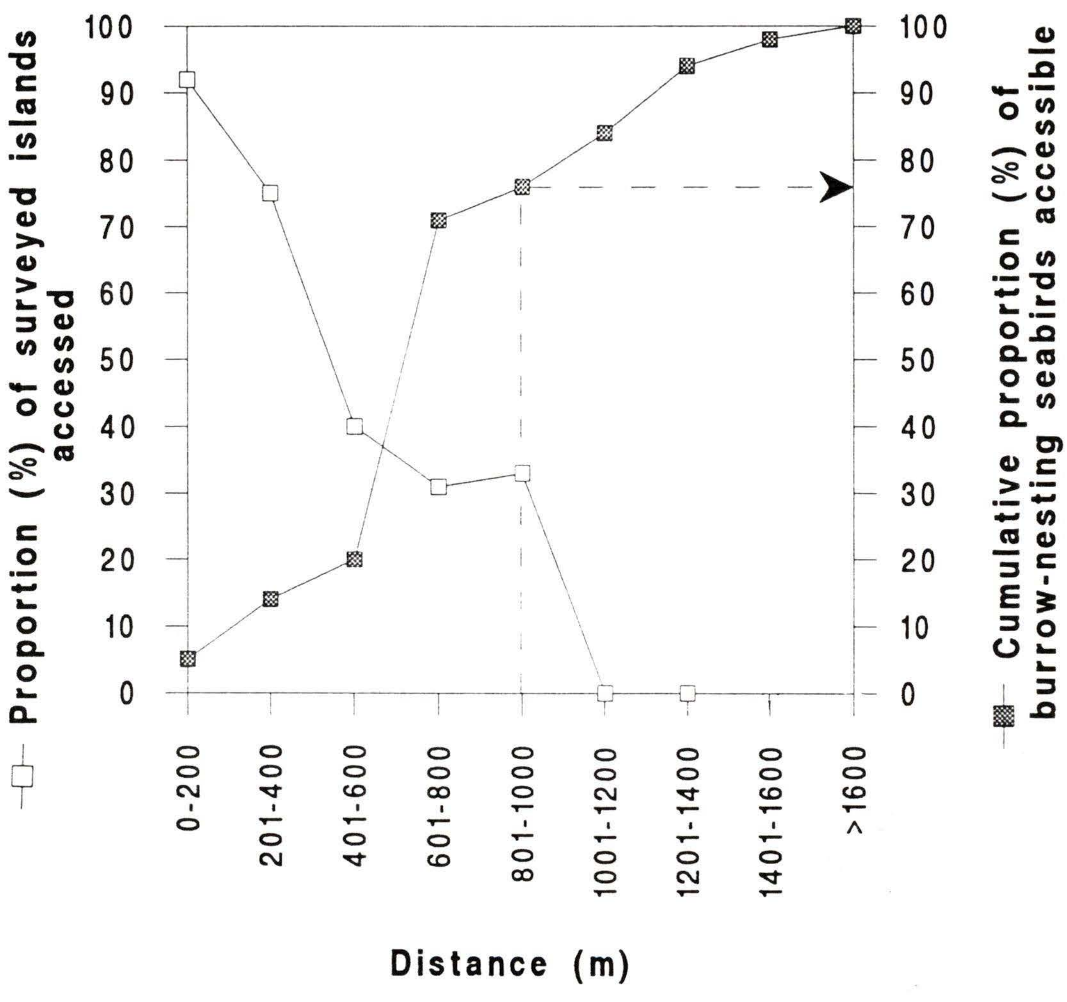
Regardless of the means by which raccoons attained their current distribution, they have crossed distances sufficient to place them on most colonies of burrow-nesting seabirds in the QCI (Fig. 21). Raccoons have currently reached at least 11 colony islands, on which 14% of the region's seabirds breed (Rodway et al. 1988). According to census data of Rodway et al. (1988), approximately 80% of all colonies of burrow-nesters, and 75% of the region's known seabird population, can be reached with over-water crossings of up to 950m. As it is unlikely that the first surveys of raccoon distribution identify the maximum limit of their over-water crossing abilities, these values represent only minimum estimates.

Approximately 50% of the total population of burrow-nesters of the QCI breed on islands from 600-800 m offshore, 87% of which are concentrated on 6 major colonies (Appendix A). The protection of these 6 colonies alone is thus of prime importance to the conservation of the region's seabird population. Relatively few burrow-nesting seabirds breed <600 m offshore (Fig. 21), but this is not necessarily a result of predation by raccoons. Historical records implicate raccoons in the local extinction of only 3 small colonies (Boulder, Sea Pigeon and Sels), but seabird populations on these islands were not sufficiently large to substantially alter the shape of the graph (Summers and Rodway 1988). Possibly the low proportion of burrow-nesters breeding on islands up to 600 m offshore stems from historic interactions with native predators, such as the black bear.

Island area

The accessibility of an island is viewed not only in terms of its offshore distance, or isolation, but also its size relative to offshore distance (MacArthur and Wilson 1967).

Figure 21. Proportion of the total burrow-nesting seabird population of the QCI accessible to raccoons with increasing over-water crossing distance.


Proportion (%) of surveyed islands accessed
Cumulative proportion (%) of burrow-nesting seabirds accessible
0
10
20
30
40
50
60
70
80
90
100
0-200
201-400
401-600
601-800
801-1000
1001-1200
1201-1400
1401-1600
>1600
Distance (m)

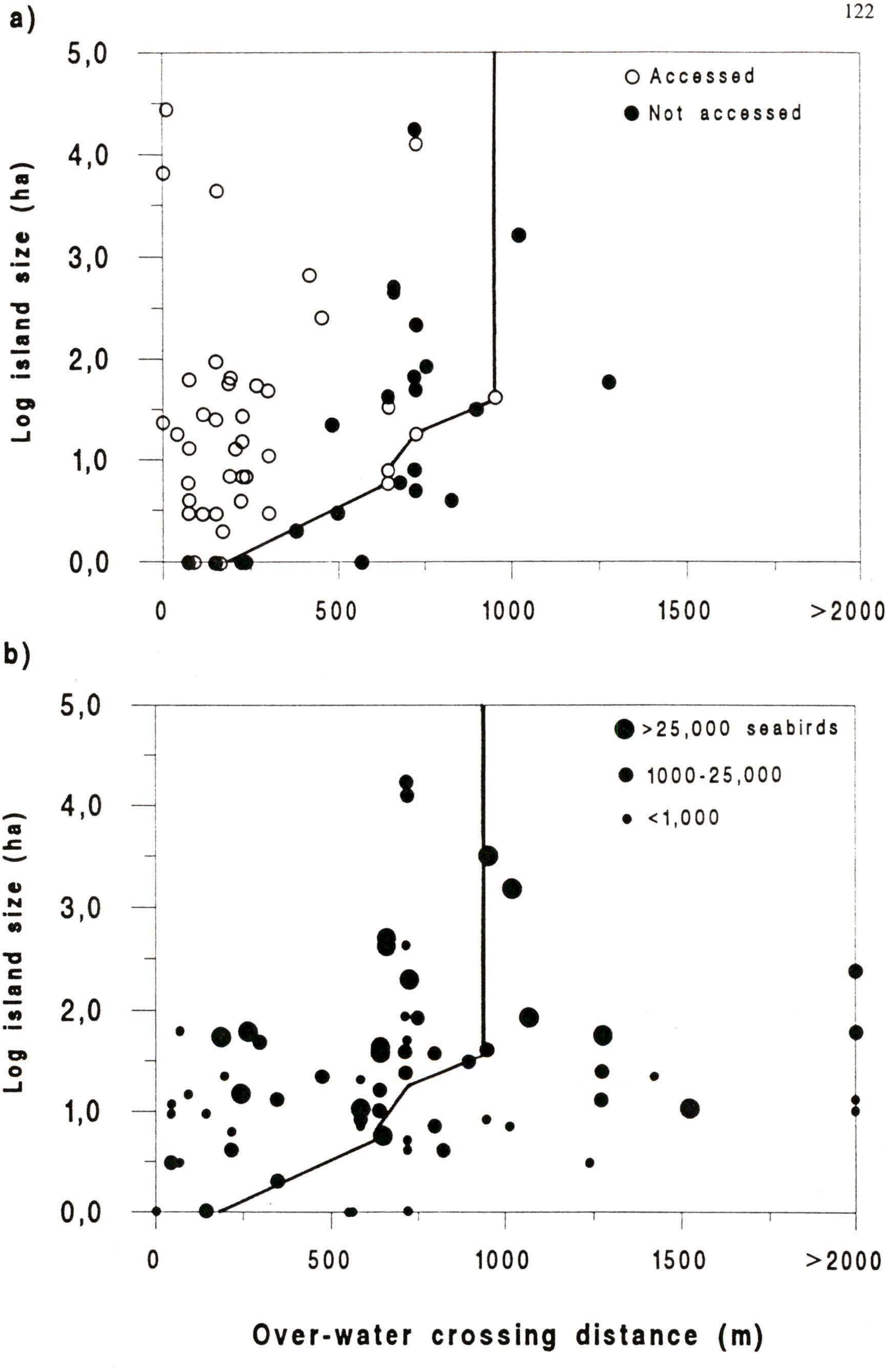
Based on passive colonization alone, small distant islands are theoretically less likely to receive dispersing individuals than large ones. Although raccoon dispersal may typically be directed rather than passive, it is nonetheless possible that for small, distant islands there is a reduced probability of "hitting the target". Raccoons may also, behaviourally, be less likely to attempt to reach islands with too small a visual profile. Despite these theoretical considerations, data collected in this study indicate that most seabird colonies are of a size which, relative to their offshore distance, are accessible (Fig. 22a,b).

Sixty-seven percent of all burrow-nesting colonies, and 74% of burrow-nesting seabirds lie within the range of island sizes and distances reached by raccoons to date. The smallest and most distant islands (<50 ha in size and >600 m over-water) reached by raccoons are characterized by biogeographic features which may have increased their probability of being reached. For example, MacArthur and Wilson (1967) postulated that the presence of other islands, in a cluster or chain of stepping stones, increases the probability that an island is reached. Clustering increases the target area, and stepping stones decrease the maximum distance which must be crossed at one time. In addition, Hanski and Peltonen (1988) have demonstrated that for shrews, dispersal in lake archipelagoes is greatest off peninsulas. The accessibility of an island to a particular species is thus mediated by a unique set of conditions, concerning the geometry of the source area, and the species' behaviour.

The most distant island known to have been reached to date by raccoons (Skedans, 950 m) lies within a cluster of islands, with a combined area of 41 ha. The second most distant islands reached are Kunghit (12,987 ha), and adjacent Ellen Island (20 ha), both 720 m offshore. Because Kunghit Island presents the dominant visual profile, Ellen Island may have been reached incidentally or secondarily. The third most distant set of islands reached lie within the "Rock Island chain" (Rock, Skincuttle, George, Jeffrey and E. Copper), a cluster of islands situated off the Pelican Point peninsula. This chain is accessible via three small, unvegetated "stepping stones", which reduce the maximum over-water crossing from 1.4 km to 640 m.

In playing a role in the colonization of islands, stepping stones also play a role in seabird conservation. Several major colonies are accessible via large stepping stone islands, some of which are known to contain raccoons (Louise, Burnaby and Kunghit), and some of which are not (Lyell, Hibben). Once colonized, these large stepping stones serve as reservoirs of dispersing animals, whereas those devoid of raccoons provide a buffer,

Figure 22. a) Size of surveyed islands reached by raccoons, relative to over-water crossing distance. b) Size of islands containing burrow-nesting seabirds, relative to their over-water crossing distance. All islands above and to the left of the solid line are within the range of sizes and offshore distances accessible to raccoons.


a)
Log island size (ha)
5,0
4,0
3,0
2,0
1,0
0,0
0
500
1000
1500
>2000
○ Accessed
● Not accessed
b)
Log island size (ha)
5,0
4,0
3,0
2,0
1,0
0,0
0
500
1000
1500
>2000
>25,000 seabirds
1000-25,000
<1,000
Over-water crossing distance (m)

delaying access to more distant colony islands. Given the infeasibility of eradicating raccoons from such large islands, maintenence of raccoon-free status on those not yet reached merits serious consideration.

The ability to reach a particular island is distinct from the ability to persist, the latter a function of opposing forces of colonization and local extinction. On very small islands, raccoons are unlikely to be able to survive year-round. Lomolino (1986) demonstrated a "minimum area effect" for the raccoon in the Thousand Island region of the Gulf of St. Lawrence. Of 19 surveyed islands, raccoons were found on only the four largest. Consistent with my results (Fig. 20), the 15 islands on which no sign was found by Lomolino (1986) were all less than approximately 1 ha. Such an effect is considered characteristic of species whose "immigration abilities are high, relative to the isolation of islands considered, but whose resource requirements are such that they can only maintain populations on the largest islands" (Lomolino 1986).

Islands which provide only marginal resources may support a small number of raccoons, vulnerable to local extinction due to both environmental and demographic stochasticity. Given the level of predation a small raccoon population can effect (Chapter 3), such islands may nonetheless experience heavy predation while colonized. In addition, such islands need not support resident raccoons if situated close to shore, and thus vulnerable to frequent transient access. Such may have been the case for three colonies which have undergone local extinction (Boulder, Sea Pigeon and Sels), all less than 7 ha, but situated within 300 m of Moresby Island.

Large islands, capable of sustaining a resident raccoon population, and thus less dependent upon periodic restocking from the mainland, will be the most vulnerable to sustained predation. Current knowledge of the habitat requirements of raccoons in the QCI is not sufficiently detailed to identify specific islands as adequate or inadequate to sustain resident populations. As a guideline, however, research at EL (Chapters 2 and 3) indicated that an island area of 60 ha was adequate to support raccoons. Thirty-one percent of all colonies, and 66% of all burrow-nesting seabirds occur on islands or islands clusters which exceed this size, and if reached may be vulnerable to sustained predation by raccoons.

Island exposure

The factor which may emerge as the most significant influence on the distribution of raccoons on the QCI, and hence on the extent of their contact with burrow-nesting seabirds, is island exposure. Taylor and Tilly (1984) cited water conditions as a factor limiting the dispersal of stoats (*Mustela erminea*) onto offshore islands of New Zealand. Whereas stoats were capable of over-water crossings of up to 1100 m in some parts of the archipelago, islands located 1000 m off more exposed coastline remain stoat-free.

Raccoons have crossed at least 950 m off the east coast of the QCI, but the maximum distance recorded for the more exposed west coast is only 220 m (Instructor Island). Four major colonies lie from 650-950 m off the exposed west coast (Frederick, Hippa, Anthony and Langara), and these colonies alone contain 40% of the total QCI seabird population. If their location renders these islands inaccessible, the severity of the raccoon's potential impact is substantially reduced. However, the west coast has not been surveyed as extensively as the east; thus, the extent to which increased exposure and decreased crossing opportunities limit access to these colonies remains to be seen.

Summary

Raccoons occur along the length of the archipelago, and the islands visited to date are not restricted to one area, but distributed widely. Given that raccoons can expand their range almost no further longitudinally, any continued range expansion will place them on an increasing number of offshore islands. Although features such as island isolation, size and exposure all have the potential to limit the accessibility of islands, results of this study indicate that the majority of burrow-nesting seabirds breed on islands which fall within the range of sizes and offshore distances accessible to raccoons.

Currently, 55% of QCI burrow-nesters breed on islands >60 ha in size, and <950 m offshore. Based on observed crossing distances and documented home ranges (Chapter 2), these islands must be considered vulnerable to both access and colonization. Smaller islands may, however, be capable of temporarily supporting raccoons, and nearshore islands may sustain heavy predation even if too small to sustain a resident predator population. If islands situated >600 m off the west coast prove to be inaccessible to raccoons, the proportion of vulnerable seabirds is reduced to 15%. However, it would be premature to suggest that these islands will remain raccoon-free on the basis of initial surveys. The distribution data presented here thus indicate that the conservation of seabird populations in the QCI is not ensured by their distribution alone, and effort will be required to limit contact between raccoons and breeding birds to ensure seabird conservation.

CHAPTER 5. CONCLUDING DISCUSSION

The severity of alien predation on seabirds is determined not by characteristics of the predator-prey interaction alone, but rather by the "interplay between a series of behavioural, ecological and geographical factors" (Moors and Atkinson 1984). Such factors determine the abundance and distribution of the introduced predator, relative to the breeding seabird population, and the level of predation they effect where and when in contact. In evaluating the potential impact of introduced raccoons on burrow-nesting seabirds of the QCI, this study has therefore described the general ecology and distribution of raccoons in this new environment, as well as their response to the presence of breeding seabirds. Results indicate that few features of the QCI environment will substantially limit contact between raccoons and breeding seabirds, and that where such contact occurs, raccoons effect severe predation. Their presence on the archipelago therefore represents essentially a "worst-case scenario" for the native, burrow-nesting seabirds of the region.

Climate is a basic feature of the environment influencing the persistence of an introduced predator population. Climatically harsh environments may limit survival of the predator beyond the first winter, resulting in a maximum of a single season of contact. There are few documented examples of an introduced predator dying out due to climatic conditions. However, the introduction of muskox to Vermont is thought to have failed due to too warm summers, and the introduction of the European pond tortoise to Britain due to too cool, cloudy summers (Diamond and Case 1986).

The natural range of the raccoon in North America encompasses a wide array of climatic conditions, with the northern limit set by the severity and duration of winter (Stuewer 1943, Cowan 1973). Although the QCI is situated near the northern limit of the range, climatic conditions are less extreme than those experienced by raccoons at similar latitudes on the mainland, because of the moderating influence of the Pacific Ocean. Given that raccoons have now been present on the QCI for approximately 50 years, they have long passed the stage where rigours of the physical environment would have exercised their effect.

As well as surviving in a new climatic regime, the introduced predator must be able to meet basic requirements for food, water, shelter and space in the new environment. If the predator is unable to meet these requirements, the population will not persist, despite the presence of breeding seabirds (Kadlec 1971). The raccoon is a generalist omnivore, noted for the variability of its diet (Kaufmann 1982). This polyphagy is advantageous in colonizing new environments (Ehrlich 1986), particularly islands, whose biota are typically characterized by impoverishment, and disharmony, the disproportionate representation of certain taxonomic groups (Williamson 1981).

The means by which raccoons meet their water requirements, and the extent to which this constrains their distribution, is unknown. However Dunson and Lazell (1982) noted that raccoons were present on numerous remote islets of the Florida Keys which lacked permanent surface fresh or brackish water, and attributed their survival to behavioural and physiological features of the species.

The raccoon is also flexible in its selection of den sites (Endres and Smith 1993), and results of this research indicate that the forested habitat of the QCI provides an abundance of the required sites. The flexibility of raccoons in meeting these basic requirements, and their non-territorial social organization, contribute to their ability to establish resident populations on small islands of the QCI, including those occupied by burrow-nesting seabirds.

The only major geographic barrier with the potential to limit contact between raccoons and burrow-nesting seabirds is the presence of open water between colony islands and the two main islands of the archipelago, Graham and Moresby. This geographic feature appears to have limited the distribution of the native pine marten, reported to avoid swimming (Dillon 1961), and not found on most offshore islands of the archipelago. Water barriers also appear to have limited the spread of introduced rats, present on islands which formerly contained villages, trading and whaling stations, but not yet detected on many adjacent offshore islands (Rodway et al. 1988). The raccoon is a proficient swimmer, however, and distributional data provided in this study indicate that many colonies lie within the range of crossing distances accessible to the species.

In some instances, the pattern of habitat use shown by alien predators has influenced their contact with breeding seabirds, and hence the magnitude of predation effected (Moors and Atkinson 1984). For example, Polynesian rats (*R. exulans*) on Kure Atoll occupied primarily vegetated habitat, and preyed little on seabirds breeding on open beaches (Woodward 1972). By contrast, Moller (1983) attributed high predation by Norway rats on shoreline nesting seabirds to the tendency of this rat to travel along avenues such as banks and tidelines. Raccoons of the QCI occupy the shoreline and adjacent island margin, which overlaps completely the location of burrow-nesting seabird colonies, and virtually guarantees contact between raccoons and seabirds where both occur together.

Where alien predators and seabirds do come in contact, the outcome depends ultimately upon the size, behaviour and dietary preferences of the predator (Moors and Atkinson 1984). The size of a predator influences both the species and life history stage of seabirds which they are capable of killing. Raccoons, a medium-sized fur-bearer, prey on all life history stages of the Ancient Murrelet, which is intermediate in size to other burrow-nesting seabirds of the region. The loss of adult birds, typically the most destructive aspect of alien predation, is exacerbated by the tendency of the raccoon toward surplus killing documented in this study. Raccoon-seabird interactions thus result in immediate and heavy losses to the breeding population, and reductions in the breeding success of the colony.

Management considerations

Conservation of the burrow-nesting seabirds of the QCI depends upon their isolation from introduced raccoons. This study has demonstrated that raccoons are in contact with breeding seabirds in many locations, and have crossed over-water distances sufficient to permit access to many more. Thus a central question emerging from this study is whether raccoons can be removed from islands housing seabird colonies and prevented from reaching those which appear within range.

The problem posed by raccoons in the QCI is not yet as severe as that faced on many of the world's islands (Eckhardt 1972, Loope et al. 1988). Much of the region is unpopulated, and a large fraction of it protected in a national park. Consequently, QCI seabirds are not subject to the habitat loss and degradation which have exacerbated seabird losses on many colonies worldwide. Other colonies worldwide have also been subject to multiple introductions, and the interaction of these exotic species has often confounded ability to identify their respective impact, and restore the original ecosystem (Taylor 1968).

Nonetheless, introduced raccoons alone pose an extremely severe threat to the conservation of QCI seabirds. The probability that a colony re-establishes itself once abandoned is unknown, and such re-establishment could occur only if the cause of the original extirpation was eliminated. Similarly, the ability to promote breeding activity in new locations, through experimental manipulation, is unknown. Conservatively, therefore, we must consider the protection of currently existing colonies as the only means of maintaining the seabird populations of the QCI. The large number of seabirds at risk, particularly Ancient Murrelets, and the increasingly wide range of the raccoon, argue for an immediate response to the problem.

The removal of alien species has been termed the "nasty neccesity" by Dobson (1990), recognizing the opposition on the part of the public to such control activities. In light of increasing public involvement in conservation issues, a balanced presentation of the facts is a prerequisite to any control activity. Moreover, it is necessary to demonstrate not only the need for the program, but also a reasonable probability of success. This depends as much upon establishing a clear set of objectives as it does upon choosing appropriate methods to eradicate the species. Such objectives may range from no action, to limited or intensive control, or total eradication (Coblenz and Baber 1987).

Total eradication on the QCI is currently infeasible, and given the level of predation only a few raccoons are capable of effecting (Chapter 3), limited control on colony islands is unlikely to adequately conserve seabird populations. It therefore seems likely that a combination of limited control on the adjacent "mainland" and intensive control or eradication on colony islands will be needed to protect seabird populations. As the funding for such programs is invariably limited, some areas may be considered too difficult to maintain raccoon-free, and hence receive little or no action.

The choice of which islands receive various treatments depends upon several factors. The value of single, large colonies must be weighed against that of numerous smaller colonies, ultimately balancing the need to protect large numbers of birds with the need to maintain diversity in colony size, location and species composition. Similarly, the cost of carrying out control activities in remote, inaccessible areas must be weighed against the number of other, perhaps smaller colonies that could be protected in the same period of time. As well, the importance of colonies already containing raccoons or other predators (e.g. rats) must be weighed against that of colonies currently predator-free. If there is only a remote possibility that either predator can be removed, the time, effort and money expended on raccoon control may be wasted.

Common methods used to remove animals include trapping, shooting and poisoning. Each differ in their effectiveness, and acceptability to members of the public. Coblenz and

Baber (1987) found that poisoning was the most effective means of removing feral pigs, and recommended a program of poisoning and shooting to reduce the population. Trapping was relatively ineffective, because of the time it took to construct and maintain traps, and the abundance of other foods. Given the low trapping success achieved in this study, it is probably inadequate for controlling raccoons.

Several biological controls have been recommended and employed, including parasites (Dobson 1988), diseases and introduced predators. The effectiveness of introduced diseases is sometimes limited by attenuation. Thus myxomatosis reduced rabbit numbers in Australia, but did not eliminate them (Fenner 1983). Similarly, feline parvo virus, which causes the disease feline panleucopaenia, reduced but did not eliminate feral cats from Marion Island (van Rensburg et al. 1987). The introduction of predators has been particularly unsatisfactory as a means of controlling introduced species, and has in many cases contributed new problems. The mongoose was introduced to Hawaii to control rodents, but instead eliminated remaining flightless rails, and carnivorous snails were introduced to control the giant African snail, but preyed on native land molluscs (Gagne 1988).

Regardless of the method chosen, removal efforts must be maintained until all animals are gone, if local control programs are to succeed. Some animals are invariably more difficult to remove than others, and if effort is reduced at this juncture the venture will be lost. In a similar fashion, if the committment to fund and conduct control activities fades in the future, the time and money expended on removal will have been wasted. In the meantime, attempts must be made to design monitoring and control programs to answer basic questions regarding the rate at which raccoons colonize islands of the QCI, as a function of size, offshore distance, and exposure. With such information, managers will be better able to evaluate the potential for success of local control efforts, and hence better able to respond to the ongoing legacy of the raccoon introduction.

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Appendix A. Breeding population, minimum over-water crossing distance (m), and area (ha) of burrow-nesting seabird colonies on QCI.

Island	BREEDING SEABIRD POPULATION*						DIST.	SIZE
	STPT	ANMU	CAAU	RHAU	TUPU	TOTAL	(m)	(ha)
Adam Rks.(2)$^{+}$					4	4	560	<1
Agglomerate(46)	11000	4400	400			15800	1275	25
Alder(54)	120	28800	6400			35320	265	62
Annette(10)				40		40	720	1
Anthony(63)	21400	400	49400	27200	32	98432	720	214
Barry(30)	1400		200			1600	350	13
Between It.(18)			200		1	201	150	9
Bischoff(13)	100	e				100	715	86
Bolkus(49)	460	19800	1920	40		22220	750	82
Bone Pt.(4)					12	12	585	8
Buck Ch.(24)	500					500	75	3
Cape Kuper(20)		20	240	20		280	585	20
Carswell(36)	540	3400	360	40		4340	475	22
Charles(23)	200			260		460	720	5
Cone It.(11)					60	60	50	9
Cox(7)	e	e	e	e	23	23	950	8
E. Copper(52)	80	8800	21800			30680	640	41
Flatrock(5)					16	16	1240	3
Frederick(66)		136000	180000			316000	655	470
George(53)	e	23200	11800			35000	640	45
Gordon(29)			1400	160	1	1561	800	38
Helgesen(51)	360	15400	7400	33200		56360	185	56
High(6)				20		20	720	49
Hippa(65)	47400	80000	25000		40	152440	655	500
Hotspring(32)	1800	12	20			1832	715	24
House(38)		5200	80			5280	715	39
Howay(28)	20	600	500			1120	900	31
Instructor(40)	3200	1520		1700		6420	220	4
Jeffrey(41)		2000	5400			7400	640	10
Kawas(31)	1400		400			1800	1275	13
Kerouard a(62)			92000		100	92100	240	15
Kerouard-b(60)			64000		800	64800	1520	11
Keyhole Rk.(8)					26	26	0	<1
Kiokathli(33)	1600		600			2200	350	2
Kunghit(50)		17600	100	5000	323	23023	720	12987
Langara(56)	e	48000	e	e	e	48000	950	3253
Langtry(51)	24600					24600	825	4
Lepas(47)	16000		400			16400	150	1

Appendix A (cont.)

Island	BREEDING SEABIRD POPULATION						DIST.	SIZE
	STPT	ANMU	CAAU	RHAU	TUPU	TOTAL	(m)	(ha)
Lihou (61)	27400	13000	22400	5400	27	68227	1060	88
Limestone(35)		3000	80	4		3084	300	48
Lost(26)	160		420			580	3750	13
Low(22)	320		60			380	2700	10
Luxmoore(44)	11400	2000	760	600		14760	585	9
Lyell(48)		21400				21400	715	17452
Marble(42)		2000	10000	400	350	12750	2750	62
Moresby Its.(19)			160	80		240	585	7
Murchison(14)		40	100			140	715	431
Nangwai(3)	4					4	50	11
Rainy(16)	200					200	720	4
Ramsay(59)		35400	25800			62200	1015	1637
Rankine(64)	28600	52000	52000			132600	1275	58
Reef(43)	280	10000	3400			13680	2925	250
Rock It.(55)	34000		10200			44200	640	6
Rogers(58)	57400	3400	80	40		60920	585	10
Saunders(12)		100				100	75	61
Seal Pt.(39)	6000					6000	50	3
Skedans(34)	2200	e	200			2400	950	41
Skincuttle(45)	8600	4400	2000			15000	640	16
Solide(37)	3200		1900			5100	800	7
St. James(9)					30	30	200	22
Tar Is.(27)	660		240			900	1425	22
Tian(17)	e		200			200	100	14
Titul(21)			340			340	1015	7
Willie(25)		20	340	160		520	220	6
Wooded(15)	200					200	510	<1
Total	312,804	542,912	600,700	74,364	1,845	1,532,625		

* all seabird population data from Rodway et al. (1988, 1990, and unpub. data)

+ numbers in parentheses refer to maps, Appendix B

STPT=Leach's and Fork-tailed Storm Petrels

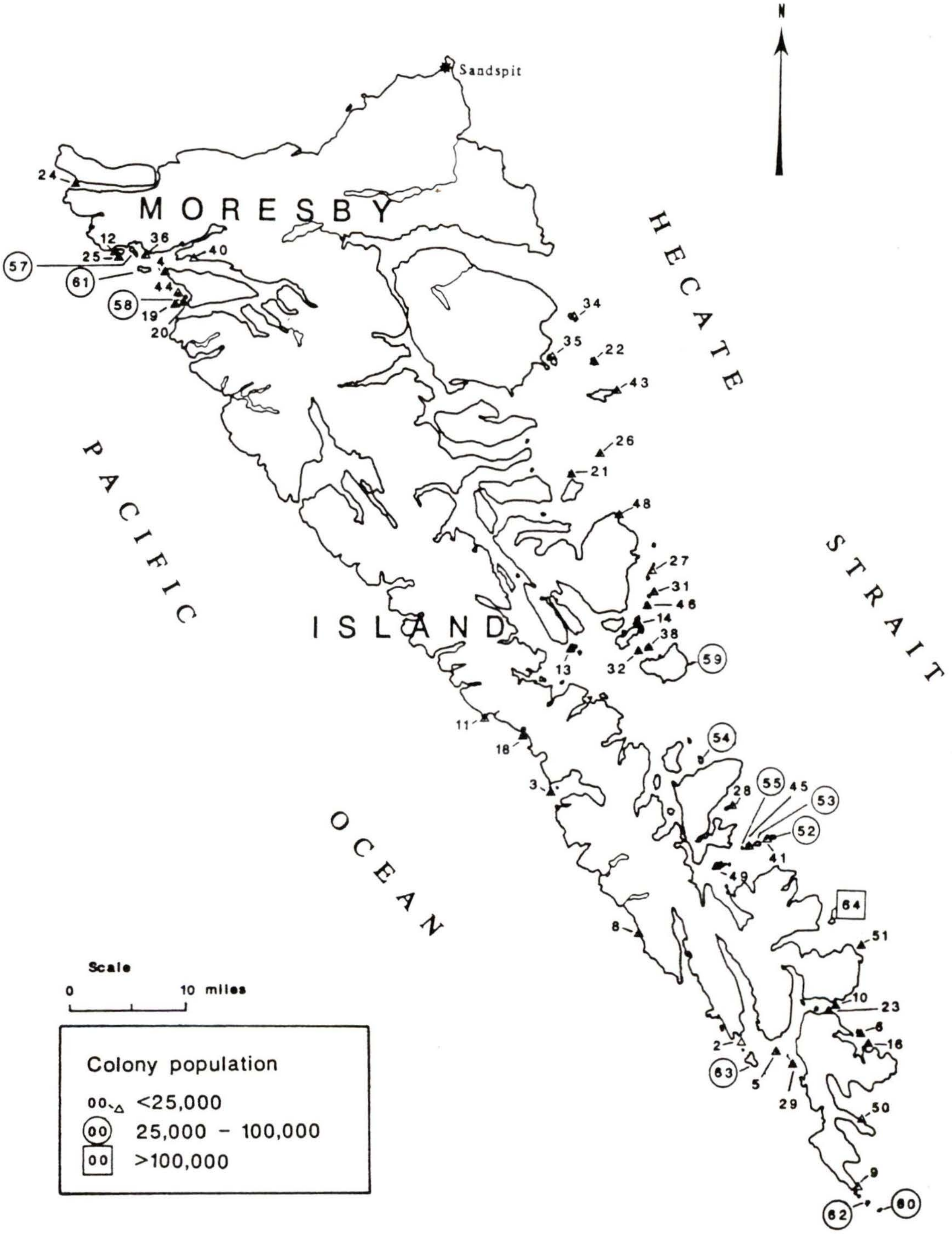
ANMU=Ancient Murrelet

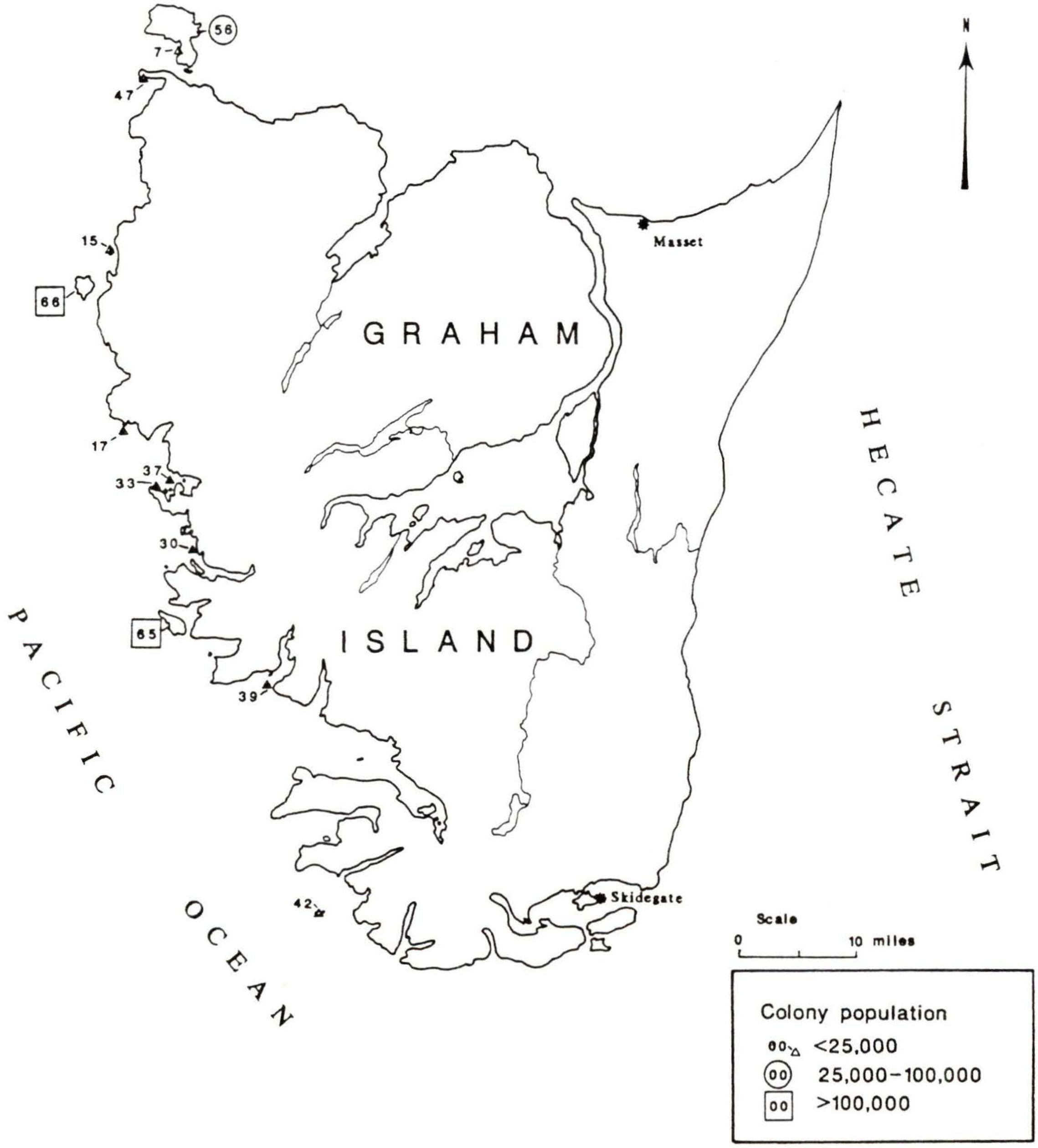
CAAU=Cassin's Auklet

RHAU=Rhinoceros Auklet

TUPU=Tufted Puffin

Appendix B. Graham and Moresby Islands and associated seabird colonies.


N
Sandspit
MORESBY
ISLAND
HECATE
STRAIT
PACIFIC
OCEAN
24
12
36
25
40
57
4
61
44
58
19
20
34
35
22
43
26
21
48
27
31
46
14
38
32
59
13
11
18
3
54
28
55
45
53
52
41
49
64
8
51
10
23
6
16
2
63
5
29
50
9
62
60
Scale
0
10 miles
Colony population
00 <25,000
00 25,000 - 100,000
00 >100,000


N
56
7
47
15
66
17
37
33
30
65
39
42
Masset
GRAHAM
ISLAND
Skidegate
HECATE STRAIT
PACIFIC OCEAN
Scale
0
10 miles
Colony population
00 <25,000
00 25,000-100,000
00 >100,000

Appendix C. Anaesthetization and measurement data for all captured raccoons.

Animal #	Weight (kg)	Dosage (mg/kg)	Dose (cc) (+booster)	Time to NBR* (min:sec)	Handling time (min.)	Tooth-wear
M75	5.50	12.0	0.66	---	25	1/8
M35	4.25	15.0	0.64	2:20	22	1/8
M95	5.50	14.5	0.80 (0.5)	---	21	1/4
M25	5.15	15.5	0.80	3:00	14	1/3
M45	3.50	15.0	0.52	3:00	18	1/8
M75	5.75	12.0	0.70	2:00	16	1/8
F65	4.50	10.0	0.45 (0.2)	---	---	4/8
F85	4.25	15.0	0.64 (0.2)	3:10	18	1/8
F15	4.25	15.0	0.64	4:15	21	---
F55	3.25	15.0	0.50	2:35	11	1/1
F-a	2.80	12.0	0.30 (0.3)	4:20	20	1/8
F-b	4.25	12.0	0.51	2:00	28	1/4
F05	5.00	13.0	0.65	2:00	20	---

Appendix C. (cont.).

Animal #	Body Length (cm) with tail	without	Neck circum. (cm)	F. Paw (cm)	R. Paw (cm)	Comments (codes below)
M75	78.5	55.0	24.0	7.7	11.0	
M35	88.0	58.0	21.0	6.3	11.5	C
M95	86.0	57.0	24.0	---	12.0	S
M25	89.0	63.0	24.0	7.5	11.0	C,S
M45	80.0	54.0	21.0	6.7	10.2	
M75	92.0	66.0	----	6.0	11.0	
F65	74.0	50.0	25.0	7.0	10.5	R
F85	81.0	54.0	21.5	6.2	10.6	R
F15	82.0	55.0	21.5	7.0	10.6	R
F55	80.0	52.0	20.5	7.0	10.0	NR
F-a	71.0	45.0	21.0	6.0	10.5	NR
F-b	72.0	50.0	24.5	6.0	9.5	
F05	89.0	61.0	22.5	6.5	10.5	

*NBR = no bite response
R = reproductive condition, darkened enlarged teats
C = convulsion
NR = non-reproductive (?)
S = heavy salivation
(tooth wear fractions represent approximate proportion of canine worn off)

Appendix D.

PREDATION TRANSECT DATA

DATE: ________ 1991

OBSERVERS ________ TRANSECT # ________

PREDATION # ________ PHOTO(S): ROLL# ________ PHOTO # ________

BEARING AND DISTANCE TO NEAREST TRANSECT LOCATION ________

FEATHERPILE ONLY ☐

CARCASS ☐

\# ADULT ☐ # CHICK ☐ ESTIMATED AGE (DAYS) ☐

BLOOD: FRESH? ☐ CONGEALED? ☐ SMELL? ☐ MAGGOTS? ☐

INVERTED? ☐ HEADLESS? ☐ SEVERED AT EYES? ☐ AT NECK? ☐

BODY INTACT ☐ BODY PLUCKED ☐ SKIN REMOVED ☐ PUNCTURES ☐

DISTANCE BETWEEN PUNCTURES, IF PAIRED (mm) ________

LOCATION OF PUNCTURES ________

DISTANCE (m): TO ASSOCATED DIGGINGS ☐ FEATHERPILE ☐ BURROW ENTRANCE ☐

BROOD PATCH ________ RIGHT WING LENGTH ________ cm BILL DEPTH ________ mm SEX ☐

WINGS MARKED: COLOUR ________ CODE: ________

EGG(S) ☐ # INTACT ☐ # BROKEN ☐ CONTENTS ________

DISTANCE (m): TO DIGGINGS ________ TO BURROW ENTRANCE ________

DIGGING(S) ☐ SIZE: [DISTANCE (m) / DEPTH (cm)]

AT BURROW ENTRANCE ________

FROM ENTRANCE TO NEST CUP ________

DIRECTLY INTO NEST CUP ________

(#) ELSEWHERE IN VICINITY ________

ROOTS TORN ☐ HAIRS PRESENT ☐ VIAL # ☐

BURROW TYPE

ROCK CREVICE ☐ OPEN GROUND ☐ TREE ROOT ☐ STUMP ☐

TREE BASE ☐ ROTTEN LOG ☐ NONE ☐

BURROW DENSITY

DISTANCE (m) FROM CENTRE BURROW TO:

1ST ________ 2ND ________ 3RD ________ 4TH ________ 5TH ________

HABITAT

(5m DIAMETER, CENTRED ON DUG BURROW IF PRESENT)

CENTRE ________ % SLOPE ________ ASPECT ________ PHOTO(S) ________

% COVER PRINCIPAL SPECIES

GROUND (≤1m)

Appendix E: Latrine and spotlight circuit values for all surveyed islands, 1990-1991.

	1990 SURVEY RESULTS		1991 SURVEY RESULTS				RACCOONS
ISLAND	Latrine circuit (m)	# Scats	Latrine circuit (m)	# Scats	Spotlight count (m)	# Raccoons	DETECTED? (Y/N)
Alder							Y
south	400	1	300	0	3710(C)	0	y
north	---	---	410	0	---	---	n
Anthony	250	0	---	---	---	---	N
Arichika	---	---	(P)	0	---	---	N*
Bischoff	300	0	---	---	---	---	N
Bolkus	300	0	375	0	5100(C)	0	N
Boulder	---	---	300	473	2360(C)	21	Y
Burnaby							Y
B. Narrows	350	188	---	---	---	---	y
Rebecca Pt.	450	227	340	205	---	---	y
Pelican Pt.	---	---	415	61	---	---	y
opp. Alder	---	---	340	182	---	---	y
Bush Rock	---	---	(C)	0	---	---	N
Carswell	---	---	---	---	2220(C)	0	N
Centre	---	---	(P)	P	---	---	Y
Charles	---	---	520	0	---	---	N
De la Beche	---	---	---	---	1050(AM)	3	Y
East Copper	500	0	---	---	---	---	N
East Limestone	---	---	300	31	3290(C)	1	Y
Ellen	250	2	440	0	---	---	Y
Frederick	---	---	1090	0	---	---	N

ISLAND	1990 SURVEY RESULTS		1991 SURVEY RESULTS				RACCOONS DETECTED? (Y/N)
	Latrine circuit (m)	# Scats	Latrine circuit (m)	# Scats	Spotlight count (m)	# Raccoons	
George	300	2?	---	---	3565(C)	0	Y?
Graham							Y
Kennecott Pt.	---	---	375	37	---	---	y
Green Rock	---	---	(C)	0	---	---	N
Harriet	---	---	360	450	---	---	Y
Helgeson	---	---	(P)	0	4260(C)	7	Y
Hibben	---	---	(P)	0	---	---	N*
High	---	---	440	0	---	---	N
Hippa	---	---	400	0	---	---	N
Hoskins	---	---	340	0	---	---	N
Howay	300	0	355	0	---	---	N
Hutton	---	---	---	---	1500(C/AM)	8	Y
Hutton Its (2)	---	---	(P)	0	(C/AM)	0	N*
Huxley							Y
west	400	0	---	---	---	---	n
south	450	0	---	---	---	---	n
sw	---	---	340	9	---	---	y
east	---	---	300	0	3750	0	n
Instructor	---	---	(P)	1?	---	---	Y?
Island Bay							
1	---	---	(P)	P	---	---	Y
2	---	---	(P)	P	---	---	Y

ISLAND	1990 SURVEY RESULTS		1991 SURVEY RESULTS				RACCOONS DETECTED? (Y/N)
	Latrine circuit (m)	# Scats	Latrine circuit (m)	# Scats	Spotlight count (m)	# Raccoons	
Island Bay Group (cont.)							
3	---	---	(P)	0	---	---	N*
4	---	---	(P)	0	---	---	N*
5	---	---	(P)	0	---	---	N*
6	---	---	(P)	P	---	---	Y
7	---	---	(P)	0	---	---	N*
8	---	---	(P)	0	---	---	N*
9	---	---	(P)	P	---	---	Y
10	---	---	(P)	P	---	---	Y
Kat	---	---	340	35	---	---	Y
Kat Rocks (2)	---	---	(C)	0	---	---	N
Koga	---	---	375	0	---	---	N
Kunghit							N
Rose Harbour	250	0	340	0	2680	0	n
Rose Islet	250	0	---	---	---	---	n
Heater Harbour	300	0	360	0	1920	0	n
Keeweenah Bay	300	0	300	0	2200	0	n
Annis Point	200	0	---	---	---	---	n
Langtry	---	---	260	0	---	---	N
Louise							Y
Skedans Pt.	---	---	300	37	---	---	y
Vertical Pt.	300	564	---	---	4310	5	y

ISLAND	1990 SURVEY RESULTS		1991 SURVEY RESULTS				RACCOONS DETECTED? (Y/N)
	Latrine circuit (m)	# Scats	Latrine circuit (m)	# Scats	Spotlight count (m)	# Raccoons	
Lyell							N
west	450	0	320	0	4125	0	n
Beresford	250	0	450	0	---	---	n
opp Faraday	300	0	300	0	---	---	n
Marco	---	---	---	---	1315(AM)	11	Y
Marco Rock	---	---	(C)	0	---	---	N
Moresby							Y
Louscoone Inlet	200	107	---	---	---	---	y
Raspberry Cove	---	---	(P)	P	2048	0	y
Hoya Passage	---	---	300	77	4875	1	y
Iron Point	375	9	375	9	---	---	y
Nakons	---	---	(P)	0	---	---	N*
Nest Islets	---	---	415(C)	0	---	---	N
Park	---	---	(P)	0	---	---	N*
Pelican Rock	---	---	(C)	0	---	---	N
Ramsay	300	0	---	---	---	---	N
Rankine	350	0	375	0	4090(C)	0	N
Rock	300	2?	750	0	---	---	Y?
Ross	250	461	---	---	---	---	Y
Saunders	---	---	(P)	0	1670	3	Y
S. De la Beche	---	---	(P)	P	825(AM)	0	Y
Sea Pigeon	---	---	300	2	1875(C)	0	Y

ISLAND	1990 SURVEY RESULTS		1991 SURVEY RESULTS				RACCOONS DETECTED? (Y/N)
	Latrine circuit (m)	# Scats	Latrine circuit (m)	# Scats	Spotlight count (m)	# Raccoons	
Section	---	---	(P)	P	415(AM)	6	Y
Sels	---	---	(P)	P	---	---	Y
Shuttle							Y
west	400	2	300	2	6000	0	y
southeast	---	---	340	0	5625(AM)	0	n
Sivart	---	---	190	0	1575(C/AM)	0	N
Skedans	---	---	(C)	0	---	---	N
Skincuttle	300	0	---	---	1800	0	N
Swan	(P)	P	340	280	---	---	Y
Talunkwan	300?	643	---	---	---	---	Y
Unnamed-CB	---	---	(P)	P	---	---	Y
Unnamed-MW	---	---	---	---	675(C/AM)	1	Y
Wanderer	---	---	(P)	P	---	---	Y
West Limestone	(P)	P	---	---	1170(C)	0	Y

(C)	-entire perimeter of island checked for scats or circumnavigated in spotlight count
(P)	-latrine circuit not done, only spot check for scats
P	-scats present in spot check
AM	-spotlight count not done, only daylight shoreline scan
*	-absence of raccoon only determined by spot check or daylight shoreline scan
?	-scat of questionable origin, raccoon suspected

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