Status of Ancient Murrelets *(Synthliboramphus antiquus)* and Upland Birds Following Eradication of Norway Rats *(Rattus norvegicus)* from Langara Island, Haida Gwaii

Mark C. Drever

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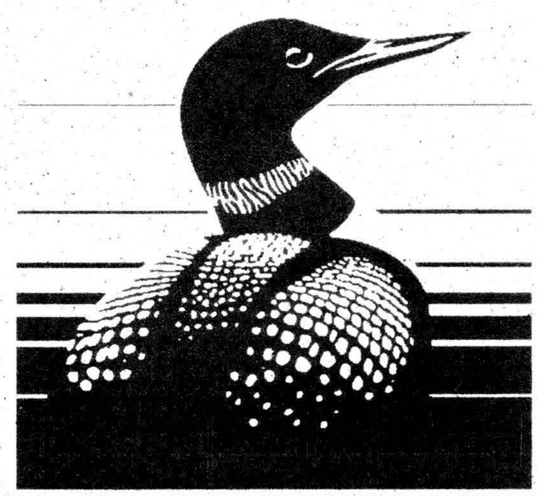
Environmental Conservation Branch



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ABSTRACT

Between 1993 and 1997, the Canadian Wildlife Service (CWS) eradicated Norway rats (*Rattus norvegicus*) from Langara Island, Haida Gwaii, to restore the island as habitat for breeding seabirds. The main eradication campaign occurred in 1995. In 1999, the Ancient Murrelet (*Synthliboramphus antiquus*) colony was re-surveyed to assess population-level response to rat eradication. In addition, surveys of upland birds carried out in 1993 were repeated, and traps were set out to determine whether rats had recolonized the island.

The Ancient Murrelet population did not differ significantly in estimated size on the 1993 and 1999 surveys (14,630 ± 2,060 pairs in 1993 and 10,365 ± 2,011 pairs in 1999; t = 1.49, df = 125, P = 0.140). However, the area covered by the colony had increased from 22.9 ha to 35.6 ha, having expanded towards the shoreline where rat densities were highest prior to eradication. Between 1993 and 1999, there were significant decreases in burrow density within the colony boundaries (1800 ± 160 to 765 ± 104 burrows per hectare; t_{125} = 5.53, P<0.001), and also in the total number of burrows present (41,220 ± 3,646 to 26,440 ± 3,595; t = 2.876, df = 125, P=0.005); however, burrow occupancy differed little (35.5 ± 3.9 % and 39.2 ± 5.5 %; t=-0.05, df=98, P=0.519). It is possible that the colony had continued to decline between 1993 and 1995, but had begun to expand after eradication of rats.

Count-plot surveys showed that several upland bird species benefited from rat eradication, including Blue Grouse (*Dendragapus obscurus*), Dark-eyed Juncos (*Junco hyemalis*), Brown Creepers (*Certhia americana*) and Red Crossbills (*Loxia curvirostra).* Conversely, there were fewer Chestnut-backed Chickadees (*Poecile rufescens*) in 1999 than in 1993. As expected, ground-nesting avian species benefited more from eradication of rats than did species that nest off the ground.

There was no evidence of rats on Langara Island, or on adjacent Lucy and Cox islands. In the absence of rats, populations of ground-nesting upland birds appear to be increasing, and the Ancient Murrelet colony appears to have stabilized. Periodic resurveys now are required to better assess responses of Ancient Murrelet populations to rat eradication, and this assessment would be strengthened by concurrent studies at colonies where murrelets have not been

subjected to predation by rats. Efforts to prevent rats from recolonizing Langara Island are essential to maintaining viable populations of Ancient Murrelets, and may enable extirpated species of seabirds to eventually recolonize the island.

RÉSUMÉ

De 1993 à 1997, le Service canadien de la faune (SCF) a éradiqué le rat surmulot (*Rattus norvegicus*) de l'île Langara, située dans l'archipel Haida Gwaii, pour y restaurer l'habitat des oiseaux de mer nicheurs. La principale campagne d'éradication a été menée en 1995. En 1999, on a effectué de nouveau un relevé dans le but d'évaluer la réaction de la population de Guillemots à cou blanc (*Synthliboramphus antiquus*) à l'éradication des rats. De plus, on a refait les relevés des oiseaux terrestres menés en 1993 et on a installé des pièges afin de déterminer si les rats avaient recolonisé l'île.

Si on compare les relevés de 1993 et de 1999, on remarque que la population de Guillemots à cou blanc ne varie pas d'une manière importante (14 630 ± 2 060 couples en 1993 et 10 365 ± 2 011 couples en 1999; t = 1,49, fd = 125, P = 0,140). Cependant, la superficie de la zone occupée par la colonie est passée de 22,9 ha à 35,6 ha, et cette zone s'est étendue vers le rivage, où les densités de rats étaient les plus élevées avant la mise en œuvre du programme d'éradication. De 1993 à 1999, on a observé d'importantes baisses de densités des terriers dans les limites de la colonie (1 800 ± 160 à 765 ± 104 terriers par hectare; t_{125} = 5,53, P < 0,001) et du nombre total de terriers (41 220 ± 3 646 à 26 440 ± 3 595; t = 2,876, fd = 125, P = 0,005); par contre, le taux d'occupation des terriers a varié quelque peu (35,5 ± 3,9 % et 39,2 ± 5,5 %; t = -0,05, fd = 98, P = 0,519). Il est probable que le déclin de la colonie s'est poursuivi de 1993 à 1995, mais que l'effectif a commencé à augmenter après l'éradication des rats.

Des décomptes par parcelle indiquent que plusieurs espèces d'oiseaux terrestres ont profité de l'éradication des rats, notamment le Tétras sombre (*Dendragapus obscurus*), le Junco ardoisé (*Junco hyemalis*), le Grimpereau brun (*Certhia americana*) et le Bec-croisé des sapins (*Loxia curvirostra).* Inversement, on a dénombré moins de Mésanges à dos marron (*Parus rufescens*) en 1999 qu'en 1993. Tel que prévu, les espèces d'oiseaux nichant sur le sol ont profité davantage de l'éradication des rats que celles nichant au-dessus du sol.

Aucune trace de rats n'a pu être relevée sur l'île Langara, ni sur les îles Lucy et Cox, qui lui sont adjacentes. En absence des rats, il semble y avoir eu une augmentation des populations d'oiseaux terrestres nichant sur le sol et une stabilisation du nombre d'individus de la colonie de

Guillemots à cou blanc. Il faut effectuer d'autres relevés périodiques pour évaluer plus précisément les réactions des populations de guillemots à l'éradication des rats; pareille évaluation bénéficierait des résultats d'études simultanées des colonies de guillemots n'ayant pas souffert de la prédation par les rats. Il est essentiel d'essayer d'empêcher les rats de recoloniser l'île Langara si on veut maintenir des populations viables de Guillemots à cou blanc et permettre ultérieurement à des espèces disparues d'oiseaux de mer de recoloniser l'île.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Langara Island in the Haida Gwaii (Queen Charlotte Islands) formerly supported one of British Columbia's largest and most diverse seabird communities (Gaston 1992). Nelson (1990) estimated that prior to the 1950s the island may have held more than 250,000 pairs of Ancient Murrelets (*Synthliboramphus antiquus*) alone. Between 1971 and 1980, breeding populations of four species of burrow-nesting seabirds disappeared from the island, and the population of Ancient Murrelets was greatly reduced (Gaston 1992). The Ancient Murrelet colony was surveyed in 1981, 1988, and 1993 (Rodway et al. 1983, Bertram 1989, Harfenist 1994), and declined steadily between each survey (Table 1). Bertram (1995) identified the likely cause of the decline as the combination of predation by introduced Norway rats (*Rattus norvegicus*) and mortality through fatal light attraction to ships and drowning in gill nets. Using funds from the Nestucca Environmental Recovery Trust Fund, the Canadian Wildlife Service (CWS) eradicated Norway rats from Langara Island between 1993 and 1997 (Kaiser et al. 1997; Taylor et al. 2000). The eradication appears to have succeeded: no signs of rats have been detected on Langara Island and its associated islands since February 1996 (Kaiser et al. 1997; Taylor et al. 2000). However, proof of the conservation value of rat eradication will be increases in breeding populations of Ancient Murrelets and re-colonization by species extirpated from the island.

Introduced rats may impact upland birds on islands through direct predation or through competition for food resources (Moors and Atkinson 1984; Martin et al. 1994). Because they have higher fecundity, population-level responses to habitat restoration may occur more quickly in upland birds (grouse, songbirds) than in seabirds (Ricklefs 1973), and thus provide more immediate information on the biological effects of rat eradication. The Canadian Wildlife Service censused songbird populations in the cedar forest of Langara Island in 1993 (Harfenist 1994), thus enabling comparison of distribution and abundance before and after eradication of rats.

Here, we report results of a visit to Langara Island by a team of biologists from the Canadian Wildlife Service in summer 1999. The team's objectives were to: (1) re-survey the Ancient Murrelet colony; (2) census the upland birds in cedar forest; and (3) determine whether rats were present. In addition, the team measured mass of chicks departing the colony, and counted the number of Ancient Murrelets flying by McPherson Point nightly, as possible alternative measures of the status of the Ancient Murrelet population.

2. STUDY SITE

Langara Island (3105 ha) is the largest island of Kiisgwaii (54°15'N, 133°00'W), a small archipelago located in Dixon Entrance off the northwest tip of Haida Gwaii (Queen Charlotte Islands), British Columbia. The archipelago includes 2 other islands, Cox (10.6 ha) and Lucy (37.2 ha) islands, as well as a few offshore islets and rocks (Figure 1). Topography and vegetation of the islands are well described by Sealy (1976), Rodway et al. (1983), and Kaiser et al. (1997). A team of 4 biologists visited Langara Island from 12 May – 9 June 1999, and was augmented by 1 volunteer between 12 May – 25 May 1999.

3. METHODS

3.1 Colony Survey

We censused the Ancient Murrelet colony using line transects with quadrats (Rodway et al. 1994) between 15 May - 2 June 1999. This method involved following compass bearings inland from the coast laying 5×5 m quadrats at 40 m intervals. A transect was considered finished when no Ancient Murrelet burrows were found on transect or in surrounding areas. Declination was set at 23° E. We repeated most transects used in 1993 as shown in Harfenist (1994) from the same starting points, and following the same bearings. Within each quadrat, we counted all burrows, and examined each hole in the ground for signs of Ancient Murrelet nesting activity. We defined an opening as a burrow if it contained past or present signs of nesting activity, including egg membranes, eggshell fragments, feathers, nest cups, fecal matter or worn, flattened earth that had been trampled underfoot (Bertram 1989). If necessary, we excavated the burrow using a trowel and pruning clippers to cut through tree roots to maximize the chance of reaching the end. In addition, we classified each burrow as occupied (i.e., contained an incubating adult, eggs, chicks, or eggshell and shell remains from freshly hatched eggs), unoccupied, or unknown (if the end of burrow could not be reached) (Gaston et al. 1988). During transects, we noted evidence of past or present nesting activity (burrowing, eggshells, droppings), and predation (bones, feather piles, dead chicks, assorted murrelet body parts), and used this information to delineate the colony boundaries. We also searched for signs of rat predation on murrelets, including dead adult birds with wounds to the nape region (typical of rat predation on seabirds, see Moller 1983, Bertram 1995), caches of eggs or chicks, and broken eggs. Eggs eaten by rats may have incisor marks and are typically chewed along the length of the egg (G. Kaiser, pers. comm.).

I calculated colony area (A) as the product of the length and average width of the area where active burrows were found. Length of the colony was calculated by following the 100’ contour line on a 1:50,000 scale map of the island, using the measure tool of ArcView GIS software (Version 3.1, Environmental Systems Research Institute, Inc.). Colony width was determined by averaging the extent of burrowing activity found on transects. For each transect, the colony boundary was assumed to extend 20 m past the end of the final quadrat within the active colony (i.e., halfway to the next, inactive quadrat). Burrow density (D) was calculated as the mean number of burrows per quadrat from quadrats that were determined to lie within the active colony. Total number of burrows (B) was calculated as the product of burrow density and colony area (D×A). Burrow occupancy, or the percentage of burrows that actually contained nesting birds (R), was determined from a sample of burrows that had been completely examined. For each quadrat that had ≥ 1 burrows that had been completely examined, i.e., burrows with known contents, we calculated burrow occupancy as the number of active burrows divided by the total number of burrows within the quadrat. The estimate of total number of nesting birds (P) is then the product of total number of burrows and burrow occupancy. The variance of total number of nesting birds is calculated as:

$$Var (P) = B2*Var(R) + R2*Var(B) – Var(B)*Var(R)$$

where B equals overall number of burrows, P is the estimate of total number of birds, and R is the occupancy rate (Rodway et al. 1994). The standard error of P is the square root of Var(P). I used t-tests to examine the significance of differences between colony parameters between years.

3.2 Chick Mass at Departure of Colony

We weighed chicks as they departed to sea to compare chick mass with data from other years (Bertram 1989; Harfenist 1994) when rats were present on Langara Island. We constructed a plastic-walled funnel (Gaston et al. 1988) along one side of a valley northwest of McPherson Point. A steep edge of the valley provided the other wall to herd departing chicks into a weighing station near the shore. We monitored the station for 2 nights on 25 May and 28 May 1999. Monitoring began at 2300 h and finished when no chicks had passed for ½ hour (0135-0230 h) or when it began to rain solidly.

All chicks passing through the station were detained for less than 5 minutes and weighed to the nearest 0.5 g with a 100-g Avinet balance (Avinet Inc., Dryden, New York, USA). After weighing, chicks were released close to shore. Any chicks captured together were released together in an effort to maintain family groups. I compared mean weight of chicks at departure between years using *t*-tests (Zar 1996).

3.3 Staging Count

For 10 minutes each night, 2 hours before sunset, we counted all Ancient Murrelets flying through the field of view of a telescope in order to compare such counts with analogous ones made in 1988 by Bertram (1989). We conducted these counts on the west shore of the south bay of McPherson Point with the telescope pointed 52°, looking just above the rocks on the south end of McPherson Point. The telescope was a 77mm diameter Kowa TSN-2 with a 30X eyepiece (Kowa Optimed, Inc., Torrance, CA). This spotting scope was later replaced with a 60 mm Bausch & Lomb Discoverer with a 15-60X zoom (Bausch & Lomb / Bushnell Optics, Richmond Hill, Ontario, Canada). I used analysis of covariance (ANCOVA) to test whether counts varied with observation date, year and the interaction (PROC GLM in SAS; Littell et al. 1991). I used the square transformation for the counts to obtain normally distributed residuals (count' = $(\text{count} + 0.5)^{0.5}$) (Zar 1996). To examine differences in mean abundance between years, I calculated least-squares means (Littell et al. 1991), which provide estimates of average counts adjusted for other terms in the model.

3.4 Songbird Surveys

We repeated the census of upland birds carried out in 1993 (Harfenist 1994), using the same fixed-radius (50 m) point count technique (Hutto et al. 1986; Manuwal and Carey 1991). Thirty plots along six transects were surveyed on 16, 18 and 29 May 1999 by counting all birds seen or heard for 20 minutes in each plot. All plots were situated in the interior of the island where forest canopy was dominated by Western red cedar (*Thuja plicata*). Plots were separated from each other by ≥400 m, and were a minimum of 150 m from nearest bog or lake, and ≥200 m from forest where the canopy was composed of Western hemlock (*Tsuga heterophylla*). Censuses were done in the morning, from sunrise to 1000 (PST), and only during days of calm weather and no rain (light mist tolerated). We found we could not reliably estimate the number of Pine Siskins (*Carduelis pinus*) and Red Crossbills (*Loxia curvirostra*) because they flew in tight flocks in and out of the plots, so these species were recorded as flocks rather than individual birds.

Changes in upland bird abundance between 1993 and 1999 were compared using two measures of abundance for each species: (1) the mean number of individual birds detected per 50-m-radius point count (×100); and (2) the proportion of plots in which a species was observed. I compared differences in mean number of birds per count using a Poisson regression model (PROC GENMOD in SAS; Agresti 1996; Stokes et al. 2001). This model was used to estimate the difference in log-transformed mean number of birds per plot between years, and I used the likelihood-ratio test (LRT) to test the significance of this difference (Agresti 1996). I also compared differences in proportion of plots where species were detected using Fisher's exact test (Agresti 1996). Arbitrarily, comparisons between years were conducted only on species that appeared in five or more plots over the two years.

I also tested whether nesting guild affected the magnitude of the difference in counts between the two years. Birds that nest on the ground were likely at higher risk of predation by rats, and may respond more strongly to rat removal, than species whose nesting habits keep them safe from rats (e.g., tree nesters). The nesting guild for each species followed Ehrlich et al. (1988) and Godfrey (1986). I ranked the difference in counts for each species between years, such that species that increased strongly received a high rank and those that decreased strongly received a low rank. I tested the hypothesis that populations of ground-nesting species would increase more than would populations of species that do not nest on the ground using a one-tailed Wilcoxon two-sample test.

3.5 Small Mammal Trapping and Indicator Baits

To determine whether rats had recolonized Langara and Lucy islands, we trapped small mammals using large Victor snap traps (EKCO Canada, Scarborough, Ontario, Canada) and indicator baits. Three sites on Langara Island (McPherson Point, Dadens, and Hazardous Cove) and one site on Lucy Island (south beach) were chosen and one 400-m trap line was established at each site (see Figure 1 for locations). The trap lines ran parallel to the shoreline and consisted of 16 stations spaced 25 m apart along the wooded coastal areas. Stations along the trap lines alternated between stations with one snap trap and stations with indicator baits. Snap traps were baited with a mixture of rolled oats and peanut butter and placed under the cover of vegetation. While checking traps, we examined the peanut butter for tooth marks and noted any changes to the bait that had occurred between checks. If a change in the bait had occurred, fresh bait was placed in traps. In addition, we set out indicator bait stations that consisted of (1) two Popsicle sticks previously boiled in bacon grease placed upright into the ground, or (2) halves of apples staked near cover 4-5 cm above the ground. Fresh apples are a preferred food of rats and their texture allows for easy identification of tooth marks (Taylor and Thomas 1989). Each series of bait stations and traps site was checked every 24 h as weather allowed for a minimum of three nights in June 1999. Juvenile rats typically disperse in early summer (Moors 1985), and thus trapping at this time allows for the most sensitive detection.

We also searched for and examined rat burrows on the beaches and nearby forest surrounding Henslung Cove, at all trapping sites, and on Cox Island, looking for evidence of recent rat activity, including fresh feces, chewed spruce cones, and tracks. We also inquired with personnel at the fishing lodges and at the lightstation for any other sightings of rats in the past year (see Figure 1 for locations).

In addition, Wayne Nelson and Keith Hodson trapped for six nights between 2 and 8 June 1999, approximately 1 km west of Fury Bay (see Figure 1 for location). Six large and six small

Victor snap traps were baited with peanut butter and evenly spaced across the mouth of a 50m wide, cliff-sided gully that runs a short distance inland (north). The traps were just inside the forest edge, atop the boulder beach.

4. RESULTS

4.1 Colony Survey

We surveyed 174 quadrats along 30 transects on the northeast side of Langara Island (Figure 1, see Appendix for details of transect locations). We resurveyed 27 of the 34 transects censused in 1993, and added three transects at the northwestern edge of the colony to better delineate the boundaries.

The area covered by the Ancient Murrelet colony had increased to 34.6 ha from 22.9 ha between 1993 and 1999, due to increases in both length (1900 to 2497 m) and average width (120.5 to 138.4 m; based on 19 transects). The increase in colony width included an expansion towards the ocean (Figure 2). The breeding area at Cohoe Point had been completely abandoned. We found 5-10 old burrows on Cohoe Point, but no evidence of nesting. While we did not examine the colony site west of Fury Bay, which had been last active in 1981, murrelets were not found using the area (W. Nelson, pers. comm.), nor were they seen on the water near Fury Bay.

Our estimates suggest that the Ancient Murrelet population declined by about 29% between 1993 and 1999, although the difference was not statistically significant (t_{125} = 1.49, P = 0.140; Table 1). Mean burrow density within the colony boundaries decreased by 58%, and this difference was significant (t_{125} = 5.53, P<0.001). The total number of burrows also declined significantly, by about 36% (t_{125} = 2.876, P=0.005). Burrow occupancy was similar on surveys in 1993 and 1999 (t_{98}=-0.05, P=0.519; Table 1).

We searched the entire contents of 137 burrows, and were able to determine the contents of 83 burrows (Table 2). Of these, 31 (37.3%) were actively used by murrelets and 52 (62.7%) showed no evidence of current use. Skeletal remains were found in only three burrows (4%), and these remains were in advanced stages of decay. One burrow with old bones had an incubating adult. We found no other evidence of rat predation of murrelets, including dead adults, or cached chicks and eggs, during quadrat searches or during transects.

4.2 Chick Mass at Departure of Colony

We caught 87 chicks over two nights at the weighing station (Table 3). Mean chick mass in 1999 was about 4% higher than that in 1989 (25.4 g [Bertram 1989]; t_{68}=3.21, P=0.002), but similar to the mean in 1993 (26.6 g [Harfenist 1994]; t_{174}=0.154, P=0.878). Inter-annual variation in chick masses at nest departure likely reflects inter-annual variation in egg mass (Gaston 1997).

4.3 Staging Count

We counted Ancient Murrelets flying by McPherson Point for 19 evenings between 15 May and 7 June 1999 (Table 4). On 25 May 1999, the viewing scope became irreparably fogged and could not be used. We resumed counts on 30 May 1999 when we received a replacement spotting scope. Counts averaged 315 Ancient Murrelets per 10-minute observation period, and ranged between 26 and 1626 (Figure 4). Number of murrelets seen nightly varied with date (F=5.84, P=0.02), year of observation (F=5.81, P=0.02), as well as the interaction between date and year (F=7.03, P=0.01). The interaction effect may have occurred because timing of breeding differed among years, or because fewer young birds visited the colony in 1999. Least-squared means of counts (± SE) were 933.7 (± 6.0) for 1988, and 226.0 (± 6.0) for 1999 (t_{41}=4.01, P=0.0003). This difference suggests a –75.8% change in counts between the two years, which is in the same direction and order of magnitude of the –57.3% difference in numbers based on colony surveys (Table 1).

4.4 Songbird Surveys

We detected 15 species of upland birds during point count surveys in 1999, the same number seen in 1993 (Tables 6 and 7). The average number of individuals seen in point-counts differed between years for five bird species. Compared to 1993, Blue Grouse, Dark-eyed Juncos, Brown Creepers and flocks of Red Crossbills occurred in greater density in 1999 (Likelihood-ratio χ^2_1>3.84,P<0.05), while Chestnut-backed Chickadees occurred in lower density (Likelihood-ratio χ

$^{2}_{1}$ = 9.19, P=0.002). Results based on proportion of counts were similar to those based on mean number of birds seen per plot: Blue Grouse, Brown Creepers, and flocks of Red Crossbills occurred on a larger proportion of plots (Fisher's Exact Test, P<0.05, Table 7).

Sum of ranks based on the magnitude of the difference in mean abundance between years was 4.5 for ground-nesting species (n=2) and 50.5 for other species (n=8). Mean scores, 2.25 and 6.31 for ground-nesters and others, respectively, were marginally significant (Wilcoxon test statistic = 4.5, P=0.058 based on a one-tailed approximation to the normal distribution, Z=-1.572). This result suggests that populations of ground-nesting birds may have increased more strongly than other upland bird species since rats were eradicated from Langara.

4.5 Small Mammal Trapping and Indicator Baits

We trapped no rats and no rat incisor marks were found on indicator baits at any of the four sites (Table 5). Only shrew feces, and snail and slug casts, were observed at the traps and indicator baits. All snapped traps were likely due to the activity of shrews as we found shrew feces on these traps. We found no tracks, rat feces, chewed spruce cones, active burrows or other evidence of rat activity in the Ancient Murrelet colony, Henslung Cove, Hazardous Cove, Cox Island, or the south side of Lucy Island. Many old rat burrows had evidence of shrew activity and/or young plants growing at the entrances, indicating an absence of rats. Personnel of the fishing lodges reported seeing no rats since 1995. Rats or their sign have not been seen at the incinerators, at the food stores or in woodpiles by the winter and summer personnel of Langara Island Lodge or the West Coast Fishing Club (D. Docherty, Langara Island Lodge, pers. comm.). Keepers of the light-station have not seen rats or their sign since February 1996 (G. Schweer, Canadian Coast Guard, pers. comm.)

None of the traps set out in Fury Bay were triggered (W. Nelson, pers. comm.).

5. DISCUSSION

Ancient Murrelet Colony

The estimated total number of Ancient Murrelets breeding on Langara Island declined by 29% between 1993 and 1999, although the difference is not statistically significant. However, the uncertainty associated with these estimates, which are products of the estimates of several other measures (colony area, burrow density, and burrow occupancy rate), must be recognized. However, the total number of burrows declined significantly, by 36%, between 1993 and 1999, and this measure tends to have less associated error (Gaston et al. 1988). Therefore, I conclude that substantially fewer murrelets nested on Langara Island in 1999 than in 1993.

Nonetheless, there are signs that the Ancient Murrelet population may be responding to rat eradication. The total area of the colony, which can be an instructive gauge of population size because it does not include uncertainties that potentially plague population estimates (Bertram 1995), increased from 22.9 ha to 35.6 ha between 1993 and 1999, and included an expansion towards the ocean (Figure 2). Ancient Murrelet colonies typically contract following rat introductions: the colonies at Dodge Point, Lyell Island (Lemon 1993) and at Luxana Bay, Khunghit Island (Rodway et al. 1988, Harfenist 1994) both contracted in width, and away from the shoreline, following the introduction of rats. Rat densities on Langara Island were higher around the shoreline than at sites further inland (Drever 1997; Drever and Harestad 1998), so that the expansion of the colony towards the shoreline may indicate that the colony is recovering. In addition, the rate of decline in number of burrows slowed between consecutive surveys, from an estimated rate of 4386 burrows per year between 1988 and 1993 to 2463 burrows per year between 1993 and 1999. This slowing in the rate of decline may indicate that the Langara Island colony is beginning to resemble Ancient Murrelet colonies without introduced predators in Haida Gwaii, which have largely remained stable or shown slight increases in population size since 1980 (Gaston 1994; Lemon and Gaston 1999).

Burrow density decreased dramatically between the 1993 and 1999 surveys, reversing a trend observed since the first survey in 1981 (Harfenist 1994). In the three previous surveys, the contraction of the colony had been accompanied by an increase in burrow density, suggesting that the two phenomena might be linked. Perhaps in the presence of rats murrelets bred more closely together to dilute predation risk on individuals, and the observed reversal of this trend represents an ecological release.

The eradication of rats from Langara Island remains in a sense an imperfect experiment because it lacks a control site for comparison; other factors, such as emigration, oceanographic effects on food availability, and losses to commercial fishing operations, also may have contributed to observed population decreases (Gaston 1992, Bertram 1995, Gaston and Adkins 1998). Ideally, the situation at Langara Island would have been compared concurrently with that at a colony where rats were still present (e.g., Khungit Island), to enable stronger inference on the role of rats in determining changes in the murrelet population. Nonetheless, it seems likely that the change in colony extent resulted at least in part from the removal of rats, since in 1999 we found no rat-chewed murrelet carcasses, a conspicuous feature of the colony in the past (Bertram 1989, Harfenist 1994).

We lack data to test whether changes in zooplankton production might have resulted in the observed changes in the murrelet population, and must infer changes in food supply based on changes in ocean conditions. In 1998, ocean temperatures around Haida Gwaii warmed considerably due to an El Niño-Southern Oscillation (ENSO) event, and several seabird colonies experienced reduced breeding success (East Limestone Island and Reef Island (Smith et al. 2000), and Frederick Island (D. Bertram and A. Harfenist, unpub. data)). Reproductive success at these seabird colonies has since returned to previous rates (J. Smith, Laskeek Bay Conservation Society, Queen Charlotte City, British Columbia, pers.comm., D. Bertram and A. Harfenist, CWS, unpub. data), but this climatic event may have affected the murrelets of Langara Island as well, and retarded population recovery.

Changes in mortality associated with commercial fishing operations may have contributed to the observed slowing in the rate of decline in the murrelet population. The number of boats around Langara Island may index potential mortality associated with commercial fishing vessels due to entanglement in gill nets and fatal light attraction (Bertram 1995). The number of fishing vessels operating around Langara Island in May and June has declined since the mid-1960s, averaging 306 vessels between 1951 and 1965, and peaking at 452 trolling and gillnetting vessels in 1963 (Bertram 1995). Between 1989 and 2001, an average of only 90 vessels operated in Area

1 (the fishing region in which Langara Island lies as designated by the Department of Fisheries and Oceans) between May and June, and has been declining since 1989 (Figure 5).

Upland birds

The increase in numbers and distribution of ground-nesting birds between 1993 and 1999 suggests that species other than Ancient Murrelets may have benefited from the eradication of rats. Blue Grouse and Dark-Eyed Juncos, both ground-nesting, year-round residents on Langara Island, may have particularly benefited from removal of rats. However, little information exists on mechanisms driving population changes of upland birds. Although populations of ground-nesting birds might have increased more strongly than those of other upland birds, several other species also increased. This suggests that a common factor was behind all population increases. Experiments using artificial nests on Langara Island have shown that rats preyed on nests located on the ground, but mainly around the coast and inland up to the hemlock/moss zone (Martin et al. 1994). Consequently, birds nesting in the cedar forest may not have experienced heavy rat predation. However, these experiments only considered egg predation, and did not examine predation on adult birds. Rats on Langara Island preyed upon adult birds other than Ancient Murrelets (Drever and Harestad 1998). A comparison of population trends for Blue Grouse and Dark-eyed Juncos on Langara Island with trends from other islands in Haida Gwaii may help to illuminate the causal mechanisms behind changes in population sizes between 1993 and 1999.

Absence of rats

While complete certainty is impossible, it appears that rats are no longer present on Langara Island (or Cox and Lucy islands), so it has the potential to regain its importance as breeding habitat for seabirds. Nearby colonies (Frederick (53°56'N, 133°10'W) and Forrester (54°51'N, 133°32'W) islands) may serve as a source of immigration of extirpated species such as Rhinoceros Auklets (*Cerorhinca monocerata*) and Cassin's Auklets (*Ptychoramphus aleuticus*). In addition, the general habitat at Langara is ideal (Kaiser and Forbes 1992), and its proximity to the continental shelf provides ready nutrients (Vermeer et al. 1985). Prevention of the re-introduction of rats currently depends on personnel of the lighthouse and fishing lodges, as well as the commercial and recreational fishers who use the island. A conservation plan detailing measures to protect the island from the re-introduction of rats and other threats needs to be developed.

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Table 1: Estimates of number of burrows, occupancy rates and total number of Ancient Murrelets based on 4 surveys conducted on the main colony of Langara Island between 1981 and 1999.

Year	Colony Area (ha)	Number of quadrats	Mean Burrow Density (burrows/ha)		Total No. Burrows		Occupancy Rate (%)		Nesting Population (pairs) [a,b]	
			Mean	SE	Mean	SE	Mean	SE	Mean	SE
1981[c]	100.8	39	820ab	139	82,650	14,010	26.3	8.0	21,740	3,570
1988[d]	46.3	31	1358bc	225	63,150	10,420	38.4	7.7	24,250	6,250
1993[e]	22.9	59	1800c	160	41,220	3,646	35.5	3.9	14,630	2,060
1999[f]	35.6	68	765a	104	26,440	3,595	39.2	5.5	10,365	2,011

[a] based on 41 quadrats in the active colony where number of burrows with known contents ≥ 1.
[b] In 1981, an additional 500 pairs estimated at Iphegenia Pt. and 50 pairs at Fury Bay. In 1988, an additional 280 pairs estimated at Cohoe Pt. In 1993, an additional 50 pairs estimated at Cohoe Pt.
[c] From Rodway et al. (1983), recalculated in Bertram (1989).
[d] From Bertram (1989).
[e] From Harfenist (1994).
[f] This study.

Table 2: Use of Ancient Murrelet burrows along 30 transects on Langara Island during May, 1999. A swath of 5 m along each transect was checked for sign of nesting activity and predation. Status refers to presence or absence of active nesting along a transect (A = active, I = inactive). Unknown burrows are those whose entire contents could not be searched. Broken eggs refer to eggs found on the ground, and includes hatched eggs. Fresh eggs are those with evidence of 1999 hatching activity, and old eggs are those from previous years. Carcasses refers to dead Ancient Murrelets found on the ground (st = sternum, w = wings, sw = single wings, h = head).

Transect	Status	Active Burrows	Inactive Burrows	Unknown Burrows	Total Burrows	Old Broken Eggs	Fresh Broken Eggs	Feather Piles	Raptor Pellets	Old Carcasses	New Carcasses	Spruce Cones
12	I	0	0	0	0	0	0	0	0	0	0	0
11	I	0	0	0	0	0	0	0	0	0	0	0
J	I	0	0	0	0	0	0	1	0	1	0	0
Z	I	0	0	0	0	0	0	0	0	0	0	0
10	A	1	3	0	4	3	0	1	0	0	0	0
42	I	0	0	0	0	0	0	0	0	0	0	0
9	A	0	1	4	5	0	1	0	0	0	0	0
K	A	1	10	1	12	3	3	5	1	0	0	0
R	A	2	3	12	17	3	12	4	0	2	1 w	0
N	A	7	2	5	14	4	4	7	0	1st	0	0
O	A	4	4	2	10	3	9	2	0	0	0	0
3	A	2	3	1	6	5	5	3	0	0	0	0
H	A	2	3	1	6	1	3	0	0	0	0	0
G	A	2	3	1	6	1	1	0	0	0	1 h	0
2	A	5	5	8	18	7	1	14	0	0	2 w	0
F	A	2	1	3	6	1	0	3	1	0	2w,2sw	0
E	A	0	5	2	7	1	0	4	0	0	1w	0
1	I	0	1	0	1	1	0	0	0	0	0	0
14	A	0	0	1	1	0	0	0	0	0	0	0
13	A	0	1	1	2	1	0	2	0	0	0	0
A	A	0	2	0	2	0	0	3	0	0	1w	0
4	A	0	0	2	2	3	0	1	0	0	0	0
D	A	3	3	8	14	0	1	0	0	0	2w	0
C	A	0	2	0	2	4	1	5	0	0	0	0
B	I	0	0	0	0	1	0	2	1	0	1w	0
L	A	0	0	1	1	1	0	0	0	0	0	0
7	I	0	0	0	0	0	0	0	0	0	0	0

Transect	Status	Active Burrows	Inactive Burrows	Unknown Burrows	Total Burrows	Old Broken Eggs	Fresh Broken Eggs	Feather Piles	Raptor Pellets	Old Carcasses	New Carcasses	Spruce Cones
8	I	0	0	1	1	0	0	0	0	0	0	0
15	I	0	0	0	0	0	0	0	0	0	0	0
16	I	0	0	0	0	0	0	0	0	0	1w	0
Totals		31	52	54	137							

Table 3: Ancient Murrelet chick mass at departure from colony on Langara and Reef Islands, Haida Gwaii, British Columbia, 1999. Langara Island data from Bertram (1989) for 1988, and from Harfenist (1994) for 1993. Reef Island data from Gaston (1997).

Year	Date	Start Time	Finish Time	N	Mean Mass (g)	S.D.	Min.	Max
Langara Island								
1999	25 May	2300	0145	46	26.3	2.0	21.5	31.5
1999	27 May	2300	0200	41	27.0	1.6	23.5	31.5
1999	Overall	-	-	87	26.6	1.9	21.5	31.5
1993	27 May – 7 June	-	-	169	26.9	1.9	21.0	30.5
1988	31 May – 6 June	-	-	37	25.4	1.9	21.5	29.0
Reef Island								
1991	N/A	-	-	589	27.1	1.9	-	-
1992	N/A	-	-	691	26.7	2.1	-	-
1993	N/A	-	-	646	27.0	2.4	-	-
1994	N/A	-	-	623	27.3	2.1	-	-
1995	N/A	-	-	550	26.7	2.2	-	-
1996	N/A	-	-	599	26.9	2.1	-	-
All years		-	-	3698	26.9	2.1	-	-

Table 4: Number of Ancient Murrelets seen staging during nightly 10-min counts with a telescope from McPherson Point, Langara Island, British Columbia, 1999.

Date	Time	ANMU	Beaufort Scale	Visibility	Comments
15 May	1945	361	2	good	
16 May	1948	6	2	good	scope at errant angle
17 May	1950	26	3	good	
18 May	1951	1626	2	fair	
19 May	1953	42	5	poor	rain hindered vision
20 May	1955	285	3	fair	
21 May	2003	217	2	fair	
22 May	1958	482	3	fair	fog
23 May	2000	81	2	bad	fog, thousands of shearwaters
24 May	2001	384	3	fair	poor light
30 May	2010	76	1	poor	fog
31 May	2011	769	6	good	
1 June	2013	355	5	fair	
2 June	2014	34	4	good	
3 June	2015	40	2	good	
4 June	2016	67	5	good	
5 June	2017	203	1	fair	rain, mist
6 June	2025	873	1	good	
7 June	2019	68	4	good	

Table 5: Results of small mammal trapping at four sites on Langara and Lucy islands, British Columbia, 1999. Each site had 8 large snap traps baited with a mixture of rolled oats and peanut butter, and 8 indicator bait stations.

Site	Dates	Number of nights	Rat sign	Shrews trapped	Empty sprung traps
McPherson Point	4-8 June	4	0	1	2
Dadens	5-8 June	3	0	8	1
Hazardous Cove	5-8 June	3	0	2	0
Lucy Island	5-8 June	3	0	1	0
Total		13	0	12	3

Table 6: Mean number of individuals of upland bird species per 50-m fixed-radius point count (n=30 for both years) in cedar forest of Langara Island, British Columbia, before (1993) and after (1999) eradication of Norway rats (*Rattus norvegicus*). Abundance expressed as mean number of individuals per plot. Bird species are sorted by nest site guild. LRT refers to the likelihood-ratio test statistic calculated from the maximized log-likelihood functions of a Poisson regression comparing differences in mean abundance between years.

		1993		1999			
Species	Guild†	Mean	SD	Mean	SD	LRT	P
Mallard	G	0.00	0.00	0.13	0.51	-	
Orange-crowned Warbler	G	0.07	0.25	0.00	0.00	-	
Blue Grouse	G	0.00	0.00	0.17	0.38	6.93	0.009
Dark-eyed Junco	G	0.13	0.35	0.47	0.73	5.88	0.02
Tree Swallow	S	0.07	0.37	0.00	0.00	-	
Chestnut-backed Chickadee	S	0.83	0.95	0.27	0.52	9.19	0.002
Winter Wren	S	0.70	0.60	1.00	0.78	1.94	0.16
Wilson's Warbler	SH	0.03	0.18	0.00	0.00	-	
Hermit Thrush	SH	0.33	0.61	0.47	0.77	0.67	0.41
Brown Creeper	T	0.00	0.00	0.13	0.35	6.93	0.009
Hairy Woodpecker	T	0.03	0.18	0.00	0.00	-	
Pine Siskin (flocks)	T	0.03	0.18	0.00	0.00	-	
Red Crossbill (flocks)	T	0.40	0.67	1.23	1.13	13.38	0.003
Townsend's Warbler	T	0.43	0.63	0.47	0.73	0.04	0.85
Golden-crowned Kinglet	T	0.60	0.77	0.60	0.73	0.00	1.00
Northwestern Crow	T	0.00	0.00	0.03	0.18	-	
Common Raven	T	0.03	0.18	0.03	0.18	-	
Varied Thrush	T	0.53	0.97	0.67	0.84	0.45	0.50
Pacific Slope Flycatcher	T	0.47	0.62	0.23	0.43	2.38	0.12
Rufous Hummingbird	T	0.00	0.00	0.03	0.18	-	

† Key: G, on ground; T, in large canopy tree; S, in snag, dead trees; SH, in shrubs, saplings, or understory trees.

Table 7: Proportion (%) of 50-m fixed-radius point counts where upland bird species where detected in cedar forest of Langara Island, British Columbia, before (1993) and after (1999) eradication of Norway rats (*Rattus norvegicus*) (n=30 for both years). Bird species are sorted by nest site guild. No. indicates the number of plots. FET P refers to the P-value associated with Fisher's Exact Test comparing the proportion of counts where species were detected between years.

		1993		1999		
Species	Guild†	%	No.	%	No.	FET P
Mallard	G	0.0	0	6.7	2	-
Orange-crowned Warbler	G	6.7	2	0.0	0	-
Blue Grouse	G	0.0	0	16.7	5	0.05
Dark-eyed Junco	G	13.3	4	33.3	10	0.12
Tree Swallow	S	3.3	1	0.0	0	-
Chestnut-backed Chickadee	S	50.0	15	23.3	7	0.06
Winter Wren	S	63.3	19	73.3	22	0.58
Wilson's Warbler	SH	3.3	1	0.0	0	-
Hermit Thrush	SH	26.7	8	33.3	10	0.79
Brown Creeper	T	0.0	0	16.7	5	0.05
Hairy Woodpecker	T	3.3	1	0.0	0	-
Pine Siskin (flocks)	T	6.7	2	0.0	0	-
Red Crossbill (flocks)	T	33.3	10	76.7	23	0.002
Townsend's Warbler	T	36.7	11	40.0	11	1.00
Golden-crowned Kinglet	T	43.3	13	43.3	14	1.00
Northwestern Crow	T	0.0	0	3.3	1	-
Common Raven	T	3.3	1	3.3	1	-
Varied Thrush	T	30.0	9	56.7	17	0.12
Pacific Slope Flycatcher	T	40.0	12	20.0	6	0.27
Rufous Hummingbird	T	0.0	0	3.3	1	-

† Key: G, on ground; T, in large canopy tree; S, in snag, dead trees; SH, in shrubs, saplings, or understory trees.

Appendix 1: Locations of transects run on Langara Island in 1999. Transects are listed from west to east. Latitude and Longitude refer to start locations (n/a indicates data not available).

No.	Bearing (°)	Length (m)	Start	Latitude (decimal degrees)	Longitude (decimal degrees)
12	202	160	Large bent spruce tree E of creek near sandy beach	54.25556	-133.02811
11	190	200	Halfway between Langara and McPherson Point, bearing 38° to third eastern Langara Rock	54.25406	-133.02364
J	260	240	at small cove, 18° to easternmost Langara Rock	54.25425	-133.01742
Z	180	160	100 m from start of transect J	54.25214	-133.01582
10	180	240	Dibrell Bay N of creek in Indian reserve	n/a	n/a
42	0	160	Start at Telegraph line, east side of creek, between transects Z and 10	n/a	n/a
9	180	280	Halfway between transects J and R, 318° to easternmost Langara rock	54.25688	-133.00706
K	180	240	250 m from start of Telegraph line, 309° to closest Langara Rock	n/a	n/a
R	200	240	from start of Telegraph line, follow 20° to the water, and back up hill on 200°	54.25424	-132.99793
N	230	320	120 m N of transect O	n/a	n/a
O	230	320	from the W bay of NoName Point	54.25082	-132.99534
3	208	280	700 m W of bay on N side of McPherson Point, ~30 m E of bay W side of NoName Point	54.25154	-132.99641
H	200	240	135 m W along ring trail from transect G	54.25082	-132.99115
G	200	200	360 m N, NW along ring trail from transect E	54.25080	-132.99035
2	200	240	Roughly halfway between transects 1 and 3	54.24983	-132.98740
F	200	200	120 m W along shore from transect E	54.24992	-132.98677
E	200	280	100 m W along shore from transect 1	54.24936	-132.98501
1	200	280	First projecting knoll on W side of bay on N side of McPherson Point	54.24863	-132.98413
14	204	160	W arm of bay W of McPherson Point at ‘flower pot’ rock	54.24896	-132.98444
13	270	320	60 m S of N corner of S bay of McPherson Point	54.24816	-132.98053
A	270	240	150 m S of N corner of the S bay of McPherson Point	54.24700	-132.98000
4	270	240	S of McPherson Point, second point N of Explorer Bay, some 70 m south of transect A	54.24651	-132.97933
D	270	200	200 m N from transect C, 100 m S of transect 4	54.24580	-132.97793
C	270	280	S of major point between McPherson Bay and Explorer Bay	54.24312	-132.97797

No.	Bearing (°)	Length (m)	Start	Latitude (decimal degrees)	Longitude (decimal degrees)
B	270	160	From point N of Explorer Bay, 200 m S along shore to start	n/a	n/a
L	270	240	100 m NE along shore from midpoint of NW side of Explorer Bay, some 175 m S from transect B	54.24202	-132.97900
7	225	280	Explorer Bay, some 5 m N of creek mouth	54.24057	-132.98120
8	185	200	S part of Explorer Bay	54.23862	-132.97748
15	315	160	Dibrell Bay N of creek in Indian reserve	54.23243	-132.97289
16	343	160	N corner of Dibrell Bay (across point)	54.23416	-132.96911

Appendix 2: Anecdotal observations of birds seen on Langara Island, 12 May – 9 June 1999. All bird species as denoted in National Geographic Society (1987).

Species	Date first seen (1999)	Comments
Inland		
Blue Grouse	13 May	
Belted Kingfisher	13 May	
Brown Creeper	13 May	
Red-throated loon	16 May	interior lake
Mallard	16 May	interior lake
Rufous-sided Hummingbird	16 May	
Redbreasted Nuthatch	17 May	
Ocean		
Northern Fulmar	-	bill found on beach
Pelagic Cormorant	12 May	
Brandt Geese	12 May	
Glacous-winged Gull	12 May	
Pigeon Guillemot	12 May	small colonies S of McPherson Pt, and W of NoName Pt.
Ancient Murrelet	12 May	
Marbled Murrelet	13 May	north of Langara rocks
White-winged Scoter	14 May	
Common Loon	15 May	
Pacific Loon	15 May	
Red-necked Grebe	15 May	
Common Murre	15 May	
Rhinoceros Auklet	15 May	
Common Merganser	15 May	
Mew Gull	16 May	
Harlequin Duck	16 May	in Explorer Bay
Whimbrel	20 May	Henslung Cove
Bufflehead	20 May	
Fork-tailed Storm-Petrel	23 May	
Black-legged Kittiwake	23 May	
Sooty Shearwaters	23 May	through 31 May, thousands
Tufted Puffin	29 May	
McPherson Point		
Black Oystercatcher	12 May	nest hatched 3 young
Ancient Murrelet	12 May	
Bald Eagle	12 May	
Peregrine Falcon	12 May	
Northern Flicker	12 May	
Northwestern Crow	12 May	
Common Raven	12 May	
Chestnut-backed Chickadee	12 May	
Winter Wren	12 May	
Golden-Crowned Kinglet	12 May	
Hermit Thrush	12 May	calling
Varied Thrush	12 May	calling
Townsend's Warbler	12 May	calling
Song Sparrow	12 May	calling
Red Crossbill	12 May	many juveniles
Hairy Woodpecker	13 May	
Brown Creeper	13 May	calling

Species	Date first seen (1999)	Comments
Ruby-Crowned Kinglet	13 May	
White-Crowned Sparrow	13 May	
Pacific-slope Flycatcher	15 May	
Swainson's Thrush	15 May	
Fox Sparrow	16 May	calling
Dark-eyed Junco	16 May	
Greater White-Fronted Goose	17 May	
Golden-Crowned Sparrow	17 May	
Savannah Sparrow	17 May	Dibrell Bay as well
Shearwaters	17 May	
Western Sandpiper	23 May	
Spotted Sandpiper	31 May	

Appendix 3: Measurements of Ancient Murrelet eggs from Langara Island, 1999. *

No.	Date	Transect	Plot	Weight	Length	Width	Collection Number*	Comments	Volume index	Density index	Calculated Age	Estimated Lay Date
1	27-May-99	O	80	43	4.93	3.58	8		63.2	0.68	-53.4	27-May-99
2	27-May-99	O	240	43	4.81	2.58	9	same parent as 3	32.0	1.34	-331.7	27-May-99
3	27-May-99	O	240	43	4.87	2.57		same parent as 2	32.2	1.34	-329.1	27-May-99
4	15-May-99	2	40	45	6.28	3.65		same parent as 5	83.7	0.54	6.6	08-May-99
5	15-May-99	2	40	46	6.32	3.71		same parent as 4	87.0	0.53	10.4	04-May-99
6	15-May-99	2	200	40	5.76	3.81		same parent as 7	83.6	0.48	31.6	13-Apr-99
7	15-May-99	2	200	39	5.96	3.77		same parent as 6	84.7	0.46	39.1	05-Apr-99
8	26-May-99	3	120	44	5.93	3.86		with hatched egg	88.4	0.50	23.3	02-May-99
9	26-May-99	3	160	42	5.98	3.59			77.1	0.54	3.6	22-May-99
10	26-May-99	3	160	42.5	5.99	3.6	7		77.6	0.55	2.5	23-May-99
11	27-May-99	N	120	44	6.04	3.85		same parent as 12	89.5	0.49	26.0	30-Apr-99
12	27-May-99	N	120	42.5	5.9	3.83	10	same parent as 11	86.5	0.49	26.2	30-Apr-99
13	27-May-99	N	120	-	-	-		piping heard from burrow	-	-	-	27-Apr-99
14	27-May-99	N	200	39.5	5.81	3.67	11	egg found cold; same parent as 15	78.3	0.50	20.5	06-May-99
15	27-May-99	N	200	39.5	5.78	3.65		egg found cold; same parent as 14	77.0	0.51	17.0	09-May-99
16	26-May-99	H	80	34.5	5.58	3.45	6	same parent as 17	66.4	0.52	14.3	11-May-99
17	26-May-99	H	80	35.3	5.65	3.47		same parent as 16	68.0	0.52	14.5	11-May-99
18	21-May-99	D	40	37.2	5.69	3.615	1		74.4	0.50	22.4	28-Apr-99
19	23-May-99	G	160	41.5	6.28	3.51	3	same parent as 20	77.4	0.54	7.2	15-May-99
20	23-May-99	G	160	43.5	6.23	3.57		same parent as 19	79.4	0.55	2.4	20-May-99
21	25-May-99	F	160	36.5	5.6	3.66	5	part of 4-egg clutch	75.0	0.49	28.1	26-Apr-99
21	25-May-99	F	160	41	5.65	3.7	4	part of 4-egg clutch	77.3	0.53	9.8	15-May-99
21	25-May-99	F	160	-	6.11	3.5		part of 4-egg clutch	-	-	-	-
21	25-May-99	F	160	-	6.47	3.58		part of 4-egg clutch	-	-	-	-
22	01-Jun-99	R	80	45	5.7	3.71		found cold	78.5	0.57	-8.43467	
23	01-Jun-99	R	120	45.5	6.06	3.61		Piping, egg difficult to measure	79.0	0.58	-9.5	02-May-99

* Collected for toxicological analysis, see Dr. John Elliott, Canadian Wildlife Service, Pacific Wildlife Research Centre, Environment Canada, RR 1, 5421 Robertson Road, Delta, BC, V4K 3N2

Figure 1: Map of Langara Island, Haida Gwaii, British Columbia, with names of locations mentioned in the text.

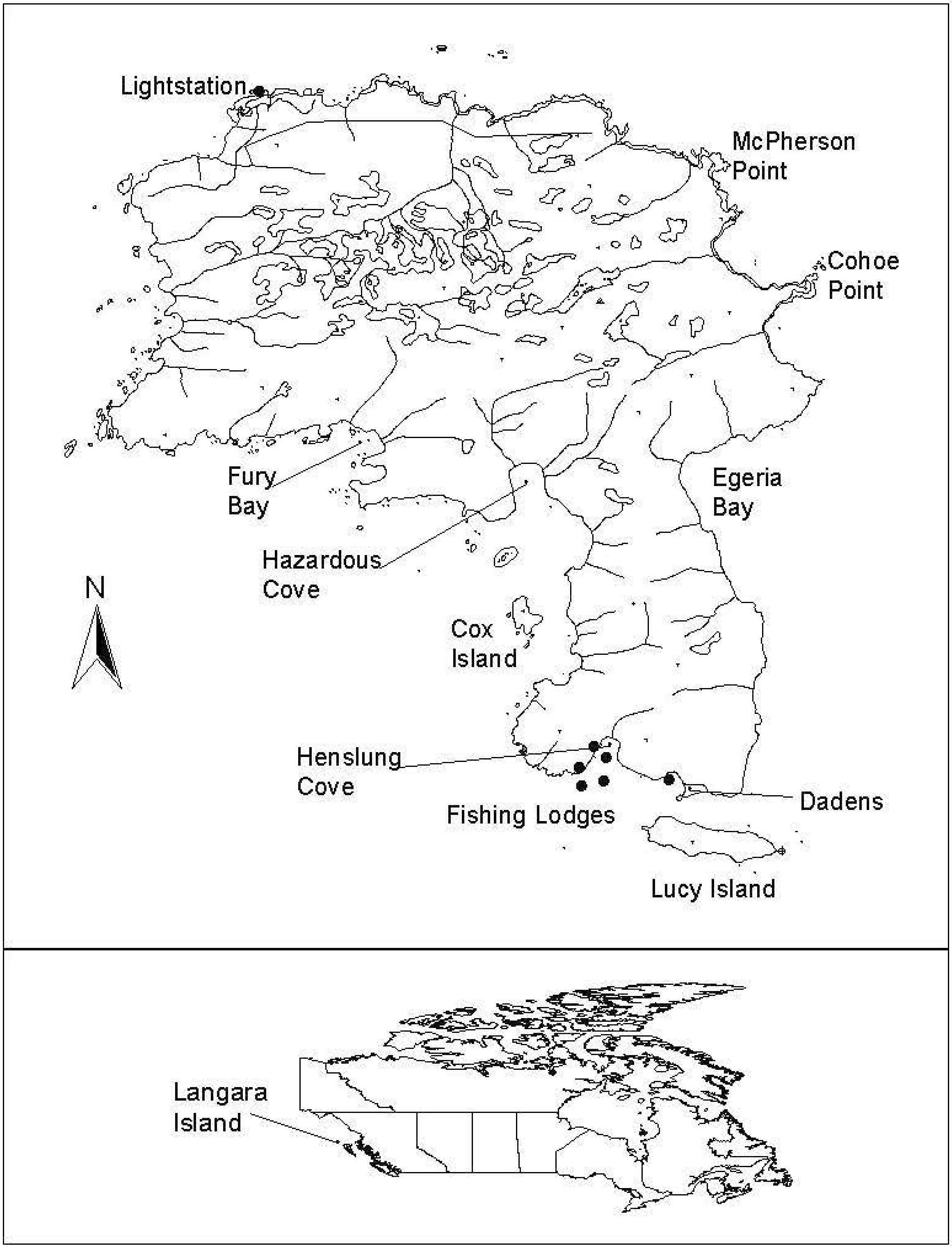

Figure 2: Location of transects used to survey the main Ancient Murrelet colony on Langara Island, British Columbia, 1999.

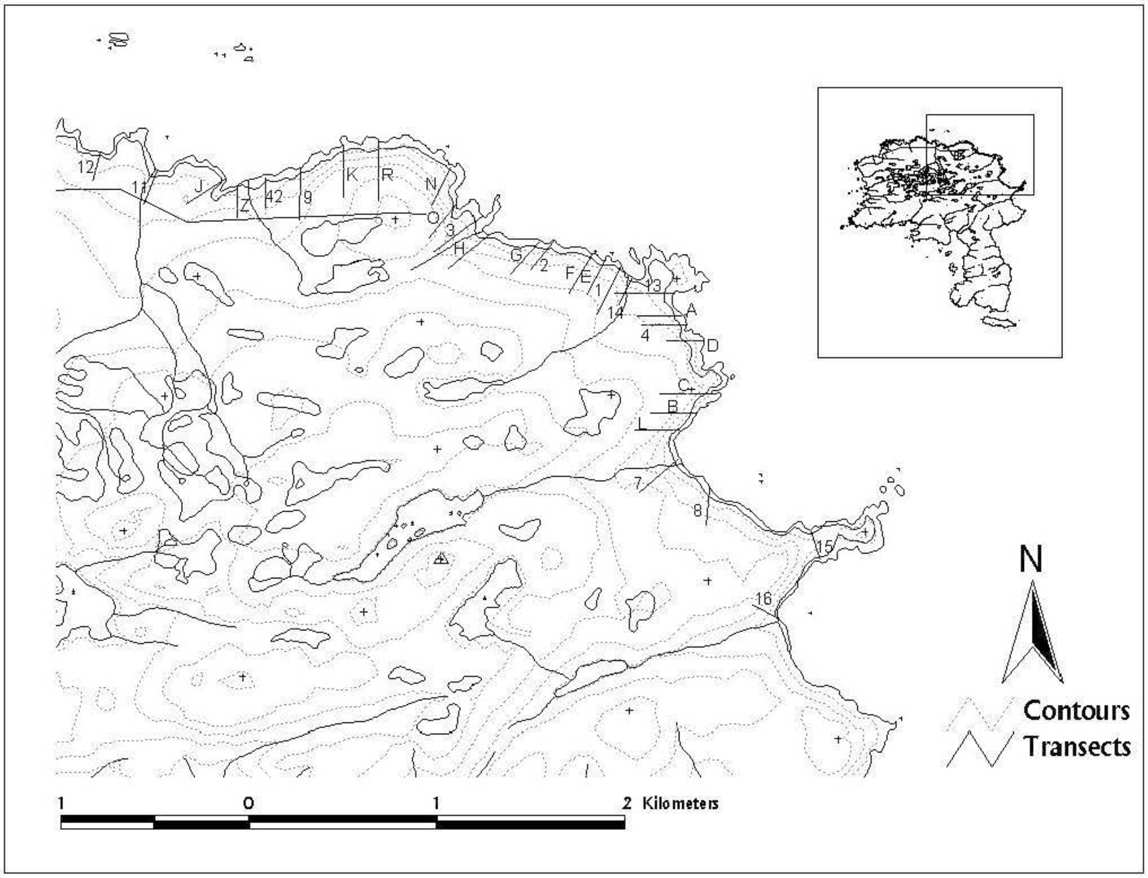

Figure 3: The extent of the Ancient Murrelet colony on Langara Island in 1993 and 1999, prior to and following eradication of Norway rats between 1993 and 1997.

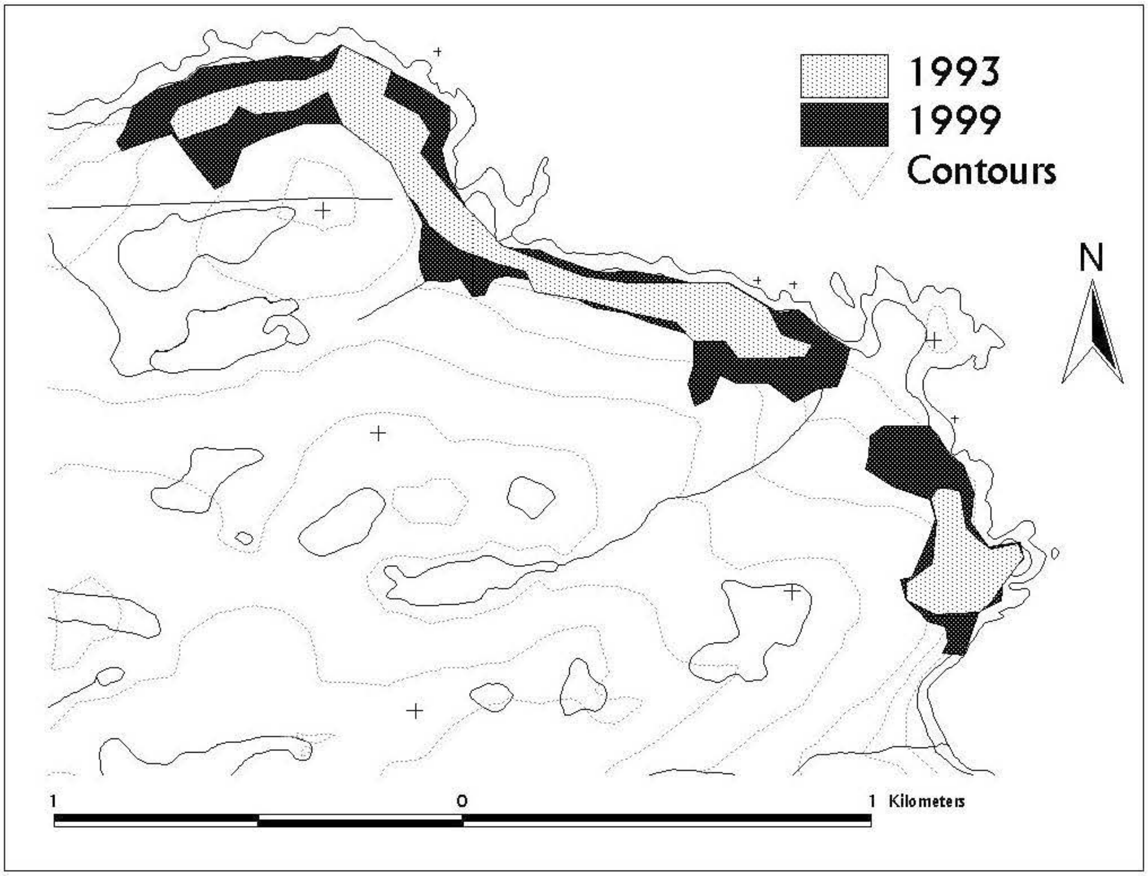

Figure 4: Numbers of Ancient Murrelets flying past McPherson Point on Langara Island to their staging area during nightly 10 min counts. Date begins on 1 January. Count of birds flying by varies with date (F=5.84, P=0.02), year (F=5.81, P=0.02), and the interaction term (F=7.03, P=0.01). R^2 = 0.42.

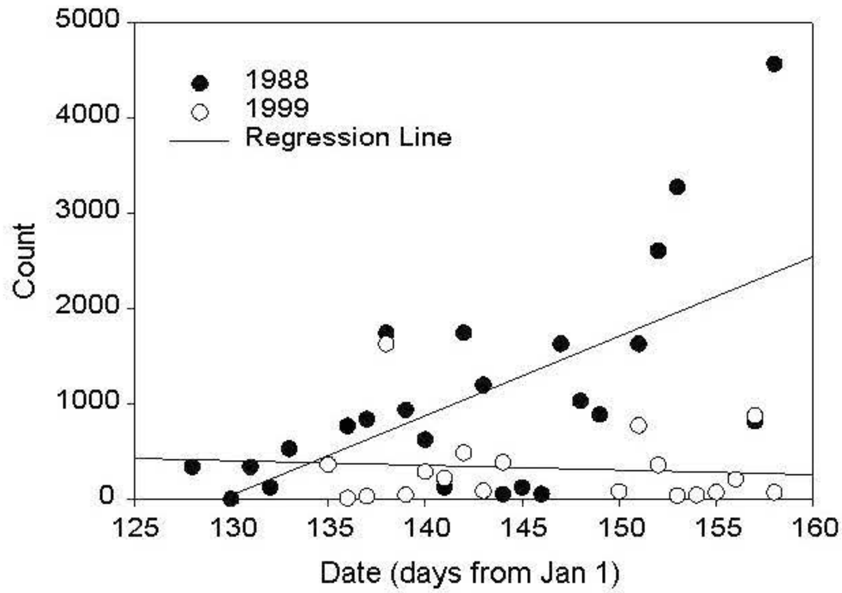

Figure 5: Number of vessels in May and June reported the Langara Island region (Statistical Area 1 of the British Columbia fisheries regions) from 1989 to 2001. Data compiled by the Pacific Regional Data Unit of the Department of Fisheries and Oceans Canada. Total number of boats has a marginally significant correlation with year (Pearson's r = -0.532, P=0.061, n=13). Total number of boats (including Gear Code 01 (clam digging)) has no signficant correlation with year (Pearson's r = -0.683, P=0.134, n=6).