Status of the Ancient Murrelet Colony on Langara Island in 2004, Nine Years After Eradication of Introduced Rats

Heidi M. Regehr, Michael S. Rodway, Moira J.F. Lemon, J. Mark Hipfner

Pacific and Yukon Region

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Heidi M. Regehr[1]
Michael S. Rodway[1]
Moira J.F. Lemon[2]
J. Mark Hipfner[2]

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[1]Box 47, Gold Bridge, BC V0K 1PO
[2]Canadian Wildlife Service, Pacific Wildlife Research Centre, 5421 Robertson Road, Delta, BC V4K 3N2

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Canada, V4K 3N2

ABSTRACT

Langara Island, situated in the northwestern corner of the Haida Gwaii archipelago, historically supported what was likely the world's largest colony of Ancient Murrelets (*Synthliboramphus antiquus*) and large populations of other burrow-nesting seabirds. Except for a remnant population of Ancient Murrelets, burrow-nesting species were extirpated following introductions early in the 20th century of Black rats (*Rattus rattus*) that were later displaced by Norway rats (*Rattus norvegicus)*. In 1995, the Canadian Wildlife Service used funds from the *Nestucca* Oil Spill Trust Fund to remove rats from Langara Island, with the aim of restoring seabird breeding habitat. We resurveyed the Ancient Murrelet colony in 2004 to determine whether the population was responding positively to rat eradication. As on previous visits in 1999 and 2002, no sign of rats was detected. In 2004, the Ancient Murrelet colony (61 ha) had expanded to twice the area it had covered in 1993. Burrow density (625 ± 85 burrows / ha) was lower than in the years 1993 and 1988 prior to rat removal, and as a result the total number of burrows in the colony (38,176 ± 5,192) was still lower than in 1993, and little changed since 1999. Burrow occupancy in 2004 (63%) was higher than in any previous year, and similar to values from rat-free colonies in Haida Gwaii, and a large proportion (91%) of breeding pairs apparently hatched their eggs. We estimated the Ancient Murrelet breeding population at 24,037 individuals ± 4,073 SE in 2004, almost double the 1999 estimate. Because the increase was due almost entirely to the high occupancy rate, it could reflect an increase in total population size, a change in the behaviour of individuals (increases in breeding propensity or burrow philopatry), or some combination of the two. In addition, we discovered a small pocket of Cassin's Auklets (*Ptychoramphus aleuticus*) nesting on the north side of the island. We conclude that rat eradication has restored seabird breeding habitat on Langara Island.

RÉSUMÉ

Dans le passé, l'île Langara, située dans l'extrême nord-ouest de l'archipel Haïda Gwaii, abritait la probablement plus grande colonie de Guillemots à cou blanc (*Synthliboramphus antiquus*) du monde ainsi que d'importantes populations d'autres oiseaux marins nichant dans des terriers. À l'exception d'une population restante de Guillemots à cou blanc, toutes les espèces nichant dans des terriers ont disparu de l'île par suite des introductions, au début du 20^{e} siècle, de rats noirs (*Rattus rattus*), qui ont été plus tard chassés par des rats surmulots (*Rattus norvegicus)*. En 1995, le Service canadien de la faune a utilisé une partie du fonds fiduciaire constitué par suite du déversement d'hydrocarbures du *Nestucca* pour éliminer les rats de l'île Langara, dans le but de restaurer l'habitat de nidification des oiseaux marins. Nous avons effectué en 2004 un relevé de la colonie de Guillemots à cou blanc pour déterminer si la population avait bénéficier de l'éradication des rats. Comme lors de nos visites de 1999 et 2002, aucun signe de la présence de rats n'a été détecté. En 2004, la superficie de la colonie de Guillemots à cou blanc (61 ha) avait doublé par rapport à 1993. La densité de terriers (625 ± 85 terriers/ha) était plus faible qu'en 1993 et 1988, années antérieures à l'éradication des rats, le nombre total de terriers dans la colonie (38 176 ± 5 192) étant encore inférieur à celui trouvé en 1993, et la situation était comparable à celle observée en 1999. Le taux d'occupation des terriers en 2004 (63 %) était supérieur à ceux mesurés dans toutes les années antérieures, et il était semblable à ceux présentés par des colonies sans rats de l'archipel Haida Gwaii; en outre, une forte proportion (91 %) de couples nicheurs ont semblé avoir réussi à couver leurs œufs jusqu'à l'éclosion. En 2004, nous avons estimé le nombre de nicheurs à 24 037 individus ± 4 073 (erreur-type), soit presque le double du nombre estimé en 1999. Comme l'accroissement était presque entièrement dû au fort taux d'occupation, il pourrait refléter un accroissement de la taille de la population totale, un changement dans le comportement des individus (accroissement de la propension à nidifier ou de la philopatrie à l'égard des terriers), où une combinaison des deux. De plus, nous avons découvert un petit groupe de Stariques de Cassin (*Ptychoramphus aleuticus*) nichant du côté nord de l'île. Nous concluons que l'éradication des rats a restauré l'habitat de nidification des oiseaux marins dans l'île Langara.

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INTRODUCTION

Langara Island, located in the Haida Gwaii archipelago (Queen Charlotte Islands), British Columbia, Canada (54° 14' N, 133° W; Fig. 1), historically likely supported the world's largest Ancient Murrelet (*Synthliboramphus antiquus*) colony, numbering perhaps 200,000 breeding pairs (Rodway 1991, Gaston 1992). It also supported large populations of other burrow-nesting seabirds. However, by the early 1990s, only a remnant population of less than 20,000 Ancient Murrelet pairs remained, and the other breeding species had been extirpated (Harfenist 1994). Predation on adult birds and their offspring first by Black rats (*Rattus rattus*), introduced to the island in the early 20th century, then by Norway rats (*Rattus norvegicus*), was likely the main cause of the declines and extirpations (Rodway 1991, Bertram 1995).

Globally, introduced predators pose the most serious threat to the conservation of island fauna, including seabirds (Burger and Gochfeld 1994), and control of introduced predators is a top priority for seabird conservation in British Columbia (Rodway 1991, Gaston 1994, Bertram and Nagorsen 1995, Hipfner *et al.* 2002). Langara Island was considered a good candidate site for a rat eradication program because of its historical significance, because Ancient Murrelets still bred on the island (providing a source population to facilitate rapid recovery), and because the breeding habitat remained excellent (Kaiser *et al.* 1997). Moreover, based on successful programs in New Zealand (Towns and Broome 2003), it was considered feasible to eradicate rats from an island as large as Langara. In 1995, funds from the *Nestucca* Oil Spill Trust Fund were used to achieve that goal, and eradication was completed by January 1996 (Taylor *et al.* 2000). Follow-up surveys in 1999 and 2002 (CWS unpublished data) found no sign of rats on the island, but a 1999 resurvey of the Ancient Murrelet colony also found little change in population size (Drever 2002).

Adaptive management calls for monitoring of the efficacy of management actions. Because the Ancient Murrelet colony had been surveyed before (1981, 1988, 1993) and soon after (1999) rat eradication, there was a valuable time-series with which to evaluate colony-level responses to rat infestation, and then eradication. In 2004, we resurveyed the Ancient Murrelet colony on Langara Island, nine years after rats had been eradicated, using the same methods as on previous surveys. By way of comparison with previous surveys, our objectives were to: (1) determine whether the Ancient Murrelet population was recovering following rat eradication; and (2) if it was, assess how the recovery was reflected in colony-based measurements (colony area, burrow density, total burrow numbers, and burrow occupancy rate); and (3) determine whether other seabird species were recolonizing the island.

METHODS

Study area and timing

Field work took place on Langara Island from 15-27 June 2004, after the Ancient Murrelet breeding season had ended. We confined our activities to the northeast corner of the island, the only area found to be active in 1999.

Survey methodology

We used the "line transects with quadrats" method outlined in Rodway *et al.* (1994) to survey the colony. At Langara, the long history of surveys has resulted in an uneven distribution of transects, and confusion over their numbering (Table 1, Fig. 2). To maximize comparability, we used 30 transects from previous surveys (Rodway *et al.* 1983, Bertram 1989, Harfenist 1994, Drever 2002). While most could be matched across years, several 1999 transect labels were confused due to a printing error in Drever (2002) (see Appendix 1). We also added two new transects in 2004: transect 5, located approximately halfway between transects 4 and 6; and transect 22, created because of confusion about where transect 13 had been placed in 1999 (Table 1, Fig. 2). Also, in 2004, transect 26 was placed about 70 m south of its position in 1999.

Locations of transects and quadrats

We laid out the 32 transects with a chain and compass using compass bearings assigned in previous years (Fig. 2, Appendix 2). All transects began at the vegetation edge, where the soil was deep enough to allow burrowing, and ran inland perpendicular to shore until no further evidence of breeding was found (see below for details). Exceptions were transects 21 and 22 that ended when they intersected transect 20 (Fig. 2). We marked transects in the field with three metal tags inscribed with the transect field label for 2004 (see Table 1) and nailed to one tree (hereafter tag tree) close to the start of the transect. We also marked transect start and end points using portable GPS units (Appendices 2 and 3), and mapped them on to a 1:12,500 air photo so that we could later compare these to plotted GPS points and evaluate GPS reliability. We recorded changes in topography along transect lines by recording slope with a clinometer at each quadrat (see below), and whenever slope changed noticeably along the transect line between quadrats. We recorded signs of activity of Ancient Murrelets or their predators (feather piles, depredated eggshells, egg membranes, pellets, carcasses, wings), and distance from the start of the transect (hereafter distance from shore), within a 5 m strip on the right side of the transect line (Appendix 4). Depredated eggshells were easily separable from hatched eggshells because when an egg is broken prior to hatching the membrane is tightly fused to the shell, whereas the membrane is thick, white, flexible, and relatively free from the shell by hatch.

We laid out 5 x 5 m quadrats at 40 m intervals along and on the right side of each transect, beginning at its start. Thus quadrat #1 ran 0 to 5 m from the vegetation edge, quadrat #2 ran 40 to 45 m from the vegetation edge, etc. In rare cases, quadrats had to be laid out on the left of, or straddling, the transect line, and before or after a 40 m interval, owing to topography. In the latter case, the quadrat was shifted in the direction requiring the least correction. The placement of the following quadrat remained unchanged, however. Occasionally, the course of a transect had to be changed; transects 11 and 13 both required slight shifts in order to navigate around ravines.

Active and inactive quadrats and determination of colony boundaries

Quadrats were considered "active" (i.e. within the colony) if they contained burrows, or if burrows were found less than halfway to the next quadrat (i.e., if burrows were located within 20 m of the quadrat along the transect). Otherwise, they were considered "inactive". As we approached the interior colony boundary we searched for burrows not only inside the 5 m strip on the right side of the transect line, but also outside this strip, on either side of the transect. If any burrows were found, this indicated that we were still within the active colony, although nesting density could be low. We always surveyed at least one quadrat beyond the interior colony boundary. These methods were designed to best delineate Ancient Murrelets colony boundaries, given that these tend to be less distinct than those of other burrowing species (Rodway *et al.* 1994).

We refer to the colony boundary closest to the ocean edge as the "shore colony boundary", and the colony boundary furthest from the ocean, but parallel to it, as the "interior colony boundary". Colony boundaries perpendicular to the ocean edge (parallel to transects) are referred to as "colony boundaries perpendicular to shore". As in previous surveys, shore colony boundaries for each transect were placed halfway between the last inactive and the first active quadrat (or at the vegetation edge if the first quadrat was active), and the interior colony boundary was placed halfway between the last active quadrat and the first inactive quadrat. The following example clarifies our methods:

> *Example*: Assume that quadrat #5 on transect A is placed 160-165 m from shore, and quadrat #6 is placed 200-205 m from shore, and that the last burrow was found 10 m past quadrat #5, at 170 m from shore. Quadrat #5 would then be considered active, quadrat #6 inactive, and the interior colony boundary for transect A would be set at 180 m from shore. However, if the last burrow was found 30 m past quadrat #5 (190 m from

shore), then quadrat #6 would be considered active, and the interior colony boundary for transect A would be set halfway between quadrats #6 and #7, at 220 m from shore.

Burrow density and occupancy

Each 25 m^2 quadrat was explored thoroughly, and the number of burrows contained within it recorded (a burrow was considered to be "in" if the quadrat contained more than half of the burrow's entrance). The following information was recorded for each burrow (see Appendix 5 for details): (1) characteristics of its location and entrance; (2) signs at the entrance such as feathers and feces; (3) its length if the end could be reached, or its minimum length if it could not; (4) its contents, if known; (5) whether any hatches were dug to attempt to reach the burrow's end (see below). We also recorded all signs of predation within each quadrat. Based on the minimum number of birds or eggs represented in the quadrat (for example, one Ancient Murrelet feather pile and two Ancient Murrelet wings would represent one bird, whereas three Ancient Murrelet wings would represent two birds), we estimated the minimum numbers of Ancient Murrelet adults and eggs depredated on the colony.

Information on burrow contents indicated whether or not the burrow had been used for nesting in that year, i.e., whether it was "occupied". A burrow was considered occupied if we reached its end and found fresh eggshell membranes (white and flexible), or cold eggs; and unoccupied if we reached its end and found neither fresh eggshell membranes nor cold eggs. We excavated hatches into burrows too long for us to reach the end directly, and afterwards patched them to maintain burrow integrity. However, we often still could not reach the end of burrows that led under live trees, roots, or fallen logs, or that were simply too deep. Therefore, we estimated occupancy based only on burrows that could be completely examined, with or without hatches. Of note, we did not include burrows in which fresh eggshell membranes or cold eggs were found, but the end of the burrow was not reached (without reaching the end, one can determine that a burrow is occupied, but not that it is unoccupied).

We also recorded other signs of nesting activity, such as worn tunnels or the presence of nesting material, droppings, feathers, tan coloured and brittle eggshell membranes from previous breeding seasons, and eggshell fragments (Appendix 5). However, these were not considered sufficient to infer occupancy in the current year.

Colony surface area, burrow density, total burrows, and breeding population

Colony area

The locations of shore and interior colony boundaries along each transect that we marked onto air photos in the field corresponded well with plotted GPS points. Thus, we considered that the GPS points were reliable, and could be used to map the colony boundaries to determine its area. Therefore, we mapped shore and interior colony boundary points along active transects by measuring known distances along transects from GPS points at the shore and interior ends (except for transects 15, 16, 17, and 18, for which we used only GPS points at the shore end of transects; see Appendix 2). However, linear field measurements cannot simply be translated onto a two-dimensional map to delineate colony boundaries because the resulting surface area is affected by the slope of the land over which field measurements were taken. We therefore first corrected all field measurements by multiplying each ground distance measurement by the cosine of the weighted average slope angle calculated from slopes recorded in the field (where the weighted average slope angle was calculated by weighting each individual slope by the proportion of the distance it represented). Once colony boundary points were in place, we used these to generate a colony surface area. Boundary points were connected as directly as possible but we also used topography to aid in the logical placement of boundaries. For example, when extrapolating the shore colony boundary between transects, the boundary was assumed to carry on along the winding shoreline at about the same distance from the shore as it had been at neighbouring transects. Exploration in the field and marking the apparent edge of nesting activity using a portable GPS unit aided in the placement of the interior colony boundary between transects 25 and 26 (Fig. 2).

Once the colony boundaries had been mapped on the airphoto, creating a two-dimensional outline of the colony, colony surface area was calculated using a digital elevation model in which the digitized colony area was overlaid onto a map complete with topographic features. We used ArcMap desktop mapping software (ESRI ArcMap 2004) and the 3D Analyst extension (ESRI 3D Analyst 2004) to produce statistics for both a two-dimensional surface area (2D) and a three-dimensional surface area that included correction for slope (3D). A 25m resolution digital elevation model (DEM) was obtained from the Province of British Columbia. The 3D Analyst extension was used to generate a triangulated irregular network (TIN) dataset by converting the raster DEM into a TIN dataset using cell centroids from the input raster. The study area boundary (soft edge) and 1:20 000 TRIM hydrology (hard edge) were added to the

TIN dataset to improve the accuracy of the 3D surface model. Surface analysis was then conducted using the area and volume statistics tool to calculate the 2D and 3D surface areas.

Number of burrows, burrow density, and breeding population

We included all active quadrats to estimate burrow density and total number of burrows. Burrow density was estimated as the average number of burrows per 25 m^2 quadrat (converted to burrows m^{-2}). The combination of colony area, density, and occupancy was sufficient to generate an estimate of breeding population, where:

$$Number\ of\ burrows = colony\ area\ \left(m^2\right) \times burrow\ density\ \left(\frac{burrows}{m^2}\right)$$

and

$$Number\ of\ breeding\ pairs = Number\ of\ burrows \times occupancy\ rate$$

Means of burrow density, occupancy, and number of breeding pairs are presented ± 1 standard error (SE; see Rodway *et al.* 1994 for method of deriving SE for the estimated number of breeding pairs).

Comparison to previous years

We compared 2004 survey results to those from 1981 (Rodway *et al.* 1994), 1988 (Bertram 1989, Rodway *et al.* 1994), 1993 (Harfenist 1994), and 1999 (Drever 2002). Due to slight differences in methods, and to recent advances in computer technology, we revised results for some surveys in order to maximize comparability. In 1981 and 1988, colony surface areas were mapped on detailed topographic maps and area estimates were generated manually using a compensating polar planimeter (Rodway *et al.* 1994). This method derives an area estimate in a fashion analogous to using the digital elevation model, so we did not redo area estimates for those years. Colony areas for 1993 and 1999 had been estimated simply as average colony length times average colony width, so for these years we plotted colony boundaries onto 2004 transects (with the exception of transect 26 which was moved 70 m north), and generated colony surface areas using the digital elevation model. We also reinterpreted colony boundaries from 1999 in 5 locations from raw data (M. Drever, unpubl. data).

One difference in field methodology needed to be considered in comparing colony areas among years. In 1993 and 1999, the first quadrat in each transect was placed 40 m from shore, not at the vegetation edge, so that colony expansion towards shore could not be detected. This was more problematic for the 1999 survey because activity was detected at the first quadrat 40 m from shore on more transects in 1999 (78%, n = 18) than in 1993 (32%, n = 19). If the first quadrat 40 m from shore was active, then the colony boundary was considered to be 20 m from shore even though it may have actually been at the shore. Thus an apparent 20 m wide expansion towards the shore between 1999 and 2004 at some locations could be due simply to differences in the location of the first quadrat.

Exploration of other parts of Langara Island

We also looked for re-colonization of Ancient Murrelets outside of the surveyed area. On 28 June, two people explored the south and central areas of Cohoe Point, which had been the southeastern extent of nesting in 1981 (Rodway *et al.* 1994; Fig. 1), for two hours. Three people also spent about 1 hour exploring the northeastern side of Cohoe Point within 100 m of the shore, site of a pocket of activity in 1988 (Bertram 1989), and 1993 (Harfenist 1994), but that had been entirely abandoned by 1999 (Drever 2002).

Signs of rat presence

We set 30 rat snap-traps baited with a mixture of oatmeal and peanut butter along the shoreline in the main part of the colony surrounding McPherson Point, and left them out for 3 nights (25-27 June). Traps were set 20 m apart and within approximately 100 m of the shoreline. We also looked for signs of rats while surveying the colony and checked all depredated eggshells found for tooth marks.

RESULTS

Colony area, total number of burrows, burrow density, and number of breeding pairs

We surveyed 196 quadrats along 32 transects (Fig. 2, Appendix 2). Twenty transects and 96 quadrats were within the active Ancient Murrelet colony (see Table 2 for colony boundaries). We counted a total of 150 burrows (Table 3), giving an average burrow density of 0.0625 ± 0.0085 burrows / m^2 (n = 96). Two-dimensional colony surface area and colony surface area corrected for slope were 558,437 and 610,814 m^2, respectively. Thus, combining burrow density and colony surface area corrected for slope, we estimated a total of 38,176 ± 5,192 burrows in the colony in 2004. We were able to reach the ends of 54 burrows and from these we estimated an occupancy rate of 0.63 ± 0.06. From these numbers, we derived an estimate of 24,037 ± 4,073 Ancient Murrelet breeding pairs on Langara Island in 2004. Of the 54 burrows in the occupancy sample, 31 contained membranes from eggs hatched in 2004, 3 contained cold eggs, and 20 were empty (Appendix 5). Thus 91% of occupied burrows showed signs of a successful hatch.

Comparison to previous years

Digital re-mapping of colony area for 1993 and 1999 resulted in some changes. Thus, estimates for colony area, total number of burrows, and breeding population sizes, but not burrow density, differ from previous reports (Harfenist 1994, Drever 2002).

The area covered by the Ancient Murrelet colony had declined to only 24% of its 1981 size by 1993, but recovered to 52% of its 1981 size by 2004 (Table 4, Figs. 1, 3, 4). (Note, however, that there had already been a very dramatic reduction in colony area by 1981). Since 1993, the colony expanded mainly into the interior of the island, towards the shore, and to the southwest of McPherson Point, while there was little expansion at its western and southern extremities (Fig. 3). However, we did find three burrows between transects 7 and 6 (Fig. 2), in a steep bank approximately 40 to 80 m from shore, and suspect that this may represent initial recolonization of that area. The colony appears to have contracted somewhat at its southeastern edge (Fig. 3).

The density of burrows in the Ancient Murrelet colony increased between 1981 and 1993, decreased between 1993 and 1999, and was similar to 1999 in 2004 (Table 4, Fig 4). Conversely, the total number of burrows decreased between 1981 and 1999, but changed little between 1999 and 2004, and was still lower in 2004 than in 1993 (Table 4, Fig. 4). However, the occupancy rate was markedly higher in 2004 (63%) than in any other survey year (26-39%). The breeding population estimate for 2004 (24,037 ± 4,073 pairs), was higher than that estimated in 1999 and similar to those from 1981 and 1988 (Table 4, Fig 4).

Exploration of other parts of Langara Island

We found no signs of Ancient Murrelet nesting activity in the areas searched around Cohoe Point.

Predation

All evidence of predation on Ancient Murrelets recorded along the transects and in the quadrats is presented in appendix 4 and 5. Using the evidence of predation recorded in 96 active quadrats (14 feather piles, 3 wings, 1 carcass, and 8 depredated eggshells (Appendix 5)), we estimated a density of 75 ± 16 birds and 33 ± 13 eggs depredated per ha within the active colony. Extrapolation over the 61.1 ha colony area indicates that 4,583 birds and 2,016 eggs had been preyed upon in the 2004 season.

Other species

We discovered a small pocket of Cassin's Auklet (*Ptychoramphus aleuticus*) burrows close to the vegetation edge on transect 10 (Fig 2). Two burrows were recorded in the first quadrat of that transect, Cassin's Auklet feather piles were found in the first and second quadrats (Appendix 5), and we counted 10 other burrows outside the quadrats within an area of approximately 25 m^2. We were unable to confirm occupancy in these burrows directly, but the distinctive signs of Cassin's Auklet (odours, feces, feathers, see Rodway *et al.* 1988) indicated that these burrows were being used.

Signs of rat presence

We did not trap any rats in 90 trap-nights. Of 30 traps, 28 were not sprung at all, and no animals were captured in the two sprung traps. The bait was completely or partially removed in 19 traps, likely by shrews (*Sorex monticolus*), as mice (*Peromyscus*) are not currently thought to reside on the island (Kaiser *et al.* 1997). We also found no sign of rats while surveying the colony. A few depredated eggshells had small tooth marks on the inside, likely from shrews. We did find two inverted Ancient Murrelet carcasses (Appendices 4 and 5), one with the body complete and the head inverted, suggesting that the predator was small; however, we were unable to determine the predator's identity. The lighthouse keepers, Gordon and Judith Schweers, who reside full-time on the island, reported no evidence of rat activity. They keep grain stores that would attract any rats present and they had not seen any.

DISCUSSION

Langara Island is among the largest islands on which rat eradication has been completed successfully (Towns and Broome 2003), and in 2004, almost a decade after the eradication, it apparently remains free of rats. An expanding Ancient Murrelet colony with a high occupancy rate and high hatching success, and apparent recolonization of the island by Cassin's Auklets, indicates that rat eradication has restored seabird breeding habitat on Langara Island.

Surveys conducted while rats were present on Langara Island (1981-1993) showed that the area of the Ancient Murrelet colony and the total number of burrows both declined steadily, mean burrow density increased (Fig. 4), and colony boundaries shifted inland (Rodway et al 1994). Contraction and concentration of the colony thus appears to be a direct response to introduced rats, perhaps because anti-predator behaviour is more effective at high densities and higher density parts of the colony are thus better able to persist under long-term rat predation. However, at no time did mean burrow density increase beyond that recorded in high-density parts of the colony in 1981, or beyond that found in high density parts of healthy colonies elsewhere in the region (Rodway *et al.* 1994). Thus increased burrow density can largely be explained by abandonment of low density habitat, although burrow density did increase in some low-density pockets in the vicinity of the remaining high-density core (Bertram 1989). Similar responses to rat predation have been observed in the Ancient Murrelet colony on Lyell Island, on the east coast of Haida Gwaii, where colony area has contracted largely due to the abandonment of low density areas, colony boundaries have shifted inland and burrow density in core areas has not increased (Rodway et al 1988, Lemon 1993). In contrast to area and density responses, there was no consistent trend in burrow occupancy rate prior to rat eradication, although throughout, the occupancy rate remained low (under 40%) relative to other rat-free Ancient Murrelet colonies (median 63%; Rodway *et al.* 1988). The population declined steadily through that period. However, by 1999, four years after rats were eradicated, two of these trends had reversed: the colony had expanded in area, especially towards shore, and burrow density had decreased within the larger area (Drever 2002). However, burrow occupancy remained low, the decline in total number of burrows continued, and the population did not increase (Drever 2002).

Colony area continued to increase between 1999 and 2004, and by 2004 it had doubled from what it was in 1993, increasing at an average rate of 3.6 ha per year during this 11 year period (although remaining small relative to its 1981 size and especially its historic size). At the same time, burrow density changed little within the larger colony area between 1999 and 2004, and in both years was similar to that recorded on the nearby, rat-free Ancient Murrelet colonies on Frederick Island and Hippa Island in the 1980s (Rodway *et al.* 1994). Most significantly, the occupancy rate increased dramatically between 1999 and 2004 (from 39 to 63%), and based on our estimate, the breeding population almost doubled.

Given that there was little increase in total number of burrows, the marked increase in population size between 1999 and 2004 was due almost entirely to the higher occupancy rate. Occupancy rate measures the number of burrows in which pairs attempt to breed and are detected, relative to the number of burrows that are maintained but do not show signs of breeding. Burrows that are maintained but unoccupied may have been: (1) used for breeding in the current year, but evidence of breeding was not detected, (2) maintained by breeders in the current year that chose not to breed or failed too early to be detected, (3) abandoned in a previous year but have persisted due to their location in stable ground, (4) abandoned in a previous year but have persisted due to their being visited and maintained by prospecting birds that did not breed in the current year, or (5) newly excavated by birds that did not breed in the current year. The non-breeding component of the population responsible for unoccupied burrows therefore consists of young, pre-breeding birds that visit the colony (Gaston 1992), and breeders that refrain from breeding in a particular year.

We lack precise species- and island-specific information on burrow persistence. Based on surveys conducted during the period of decline on Langara Island, observers can easily identify abandoned areas less than 5 years after birds stop using them (Harfenist 1994), and all evidence of burrowing disappears from abandoned areas in less than 10 years (Rodway *et al.* 1994). We have no way of knowing how often occupied burrows are misclassified as unoccupied. Given those uncertainties, we will concentrate mainly on factors related to the ratio of breeding:non-breeding population components.

Prior to rat eradication on Langara Island, burrow occupancy was probably lower than is typical for healthy Ancient Murrelet colonies due to reduced size of the breeding component of the population relative to the non-breeding component, for a number of reasons. First, rats killed a substantial number of Ancient Murrelets, decreasing local adult survival (Bertram 1989, Drever and Harestad 1998, Hobson *et al.* 1999). Predation rates were especially high in areas where the occupancy rate was low, and in abandoned parts of the colony (Bertram 1989). Second, breeding propensity of Ancient Murrelets would likely be low in the presence of an introduced predator, and more adults may have emigrated away from Langara Island to breed. Third, due to breeding failure, more adults may have abandoned old burrows and dug new ones, thus creating additional burrows that would appear active but were unoccupied (Bertram 1989). Fourth, given that prospecting birds visit multiple colonies before settling at a site to breed (Gaston 1992), they may have chosen to recruit elsewhere at higher than normal rates, after assessing predation risk on Langara Island (Thibault 1995), which would have lowered recruitment to Langara Island. Finally, because many of the pre-breeding birds visiting a colony derive from other nearby colonies (Gaston 1992), and assuming that these colonies are healthy, the numbers of prospecting birds (which form part of the non-breeding component of the population that maintain unoccupied burrows) would remain relatively unchanged in spite of poor productivity on Langara Island. Once rats were eliminated from the island, we would expect adult survival, breeding propensity, emigration, burrow philopatry, and recruitment to return to normal levels, the proportion of breeders to non-breeders to increase, and thus occupancy rate to return to normal.

Low occupancy in 1999 suggests that other environmental conditions delayed recovery, or that some of the factors responsible for reduced occupancy prior to rat removal were still operative in 1999, and that a period of time may be required before a stressed colony will resume normal breeding activities after the predator has been removed. The fact that total number of burrows declined in 1999 relative to 1993 suggests that adult mortality and emigration were still greater than recruitment in 1999, and that the population was not yet in a recovery phase.

That leaves the question of to what extent the apparent doubling in Langara Island's Ancient Murrelet breeding population between 1999 and 2004 reflects true population growth. If all of the observed increase in breeding population was due to population growth, this would represent a very rapid increase for a long-lived species with high adult survivorship and low recruitment rate. Such rapid rates of growth have been reported at other alcid colonies, but generally require considerable immigration (Harris 1983, 1984, Hudson 1985). However, larger clutch size (2 eggs), higher recruitment (Gaston 1990), and density dependent effects from reduced colony size may have enabled the Ancient Murrelet population on Langara Island to increase more rapidly than would be possible for other alcids. Substantial movement of banded individuals (Gaston 1992) and high rates of gene flow (Pearce *et al.* 2002) among breeding Ancient Murrelet colonies suggest that rapid population growth through immigration may be feasible. However, the fact that the number of burrows did not increase between 1999 and 2004 suggests that recruitment had not increased markedly, and we think that the larger breeding population was most likely due to a combination of population growth, effected by increased adult survival and reduced emigration, and changes in behaviour, specifically greater breeding propensity and burrow philopatry.

Some factors that may hinder the recovery of the Ancient Murrelet colony on Langara Island are fishing activity in the vicinity of the island and predation by natural predators. Commercial fishing operations were cited as a significant source of mortality of Ancient Murrelets in the 1950s and 1960s (Bertram 1995). Although commercial fishing has declined since the 1960s, sport fishing activities around Langara Island and associated boat traffic have become intense near the traditional gathering grounds of Ancient Murrelets (Sealy 1976, Gaston 1992, Rodway *et al.* 1994), which may be important for mate sampling, pair formation, or other social functions (Gaston 1992). Recorded rates of predation on adult murrelets and on eggs was high on Langara Island relative to that on nearby colonies both before (Rodway *et al.* 1994) and after (this study) rat removal. Rats were thought to be responsible for 18% and 29% of the evidence of depredated adults found on the colony in 1981 and 1988, respectively (Bertram 1989, Rodway *et al.* 1994). Thus the 75 ± 16 birds per ha reported for 2004 is consistent with the rates of predation thought to be due to natural predators in 1981 and 1988. The lower density of depredated eggs in 2004 (33 ± 13 eggs/ha) than in 1981 and 1988, supports the contention that rats were responsible for much of the egg predation recorded in those years

(Rodway *et al.* 1994). Most predation remains on the colony in 2004 and previous years were Ancient Murrelet feather piles, likely left by Bald Eagles (Rodway *et al.* 1994). In addition, large numbers of Ancient Murrelets are taken off the colony by Peregrine Falcons (Nelson 1990). We do not know why predation by natural predators should be relatively high on the Langara Island Ancient Murrelet colony, but this may play a role in the speed at which the colony can recover.

The discovery of a small pocket of Cassin's Auklet burrows on the northern side of Langara Island suggests that re-colonization by one extirpated seabird species has occurred, and suggests that seabird nesting habitat has been restored on Langara Island. Cassin's Auklets were first documented on Langara Island in 1926 (Campbell *et al.* 1990), and while numerous historically, they apparently had been extirpated by 1981 (Rodway *et al.* 1994, Rodway 1991). Other burrow-nesting species abandoned Langara Island decades ago, and only Ancient Murrelets persisted. Species that raise their chicks to fledging in their burrows, and leave them unattended much of the time, are more vulnerable to rats than those that do not (Moors and Atkinson 1984, Atkinson 1985). Thus the precocial departure of their chicks might have enabled Ancient Murrelets to persist in the presence of rats. Recolonization by a burrow-nesting species that raises their chicks to fledging on the island would therefore represent a significant milestone in the recovery of Langara Island.

RECOMMENDATIONS

Results from this study indicate that nesting seabirds are responding to the eradication of rats and provide an excellent prognosis for the recovery of the Langara Island colony to its historic importance. However, there are factors which potentially may limit recovery to historical levels. The construction of fishing lodges has eliminated habitat in the middle of what was formally a dense part of the historical Ancient Murrelet colony (Sealy 1976). Human traffic to those lodges may re-introduce rats to the island in time, and raccoons, which are common on the main shore of Graham Island and are capable of crossing to Langara Island, also pose a serious threat (Rodway 1991, Gaston 1994, Hartman and Eastman 1999). To mitigate factors which have the potential of limiting recovery to historical levels and to monitor that recovery, we recommend

> continued collaboration with personnel at the fishing lodges to ensure that a mechanism is in place to rapidly detect re-introductions of rats or arrival of raccoons, and to allow a quick response if any were detected.

investigation of the potential impacts of lights and activity around the fishing lodge and boat traffic around the island within the murrelet’s gathering grounds.
periodic visits to the island to survey for rats in the colony and to monitor the recovery of Ancient Murrelet and Cassin’s Auklet colonies.
in future surveys of the nesting colony, that the irregular distribution of transects used in 2004 be abandoned and a new set of transects be established that better represent all colony areas.
that permanent plots be established throughout present colony areas and in currently unoccupied habitat near colony boundaries to help monitor future changes in burrow density and colony expansion. These would also be valuable for monitoring potential expansion of the small pocket of Cassin’s Auklets discovered in 2004.

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REFERENCES

Atkinson, I.A.E. 1985. The spread of commensal species of *Rattus* to oceanic islands and their effects on island avifaunas. Pp. 35-81 *in* P.J. Moors (Ed.). Conservation of island birds: case studies for the management of threatened island species. ICBP Technical Publication No. 3.

Bertram, D.F. 1989. The status of Ancient Murrelets breeding on Langara Island, British Columbia, in 1988. Technical Report Series No. 59. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

Bertram, D.F. 1995. The roles of introduced rats and commercial fishing in the decline of Ancient Murrelets on Langara Island, British Columbia. Conservation Biology 9: 865-872.

Bertram, D.F. and D.W. Nagorsen. 1995. Introduced rats, *Rattus* spp., on the Queen Charlotte Islands: Implications for seabird conservation. Canadian Field-Naturalist 109: 6-10.

Burger, J. and M. Gochfeld. 1994. Predation and effects of humans on island-nesting seabirds. Pp. 39-67 *in* D.N. Nettleship, J. Burger, and M. Gochfeld (Eds.). Seabirds on islands: threats, case studies and action plans. BirdLife International. Cambridge.

Campbell, R.W., N.K. Dawe, I. McTaggart-Cowan, J.M. Cooper, G.W. Kaiser and M.C.E. McNall. 1990. The birds of British Columbia, Volume II. British Columbia Museum in association with Environment Canada, Canadian Wildlife Service. Victoria, British Columbia.

Drever, M.C. 2002. Status of Ancient Murrelets (*Synthliboramphus antiquus*) and upland birds following eradication of Norway Rats (*Rattus norvegicus*) from Langara Island, Haida Gwaii. Technical Report Series No. 385. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

Drever, M.C. and A.S. Harestad. 1998. Diets of Norway Rats, *Rattus norvegicus*, on Langara Island, Queen Charlotte Islands, British Columbia: Implications for conservation of breeding seabirds. Canadian Field-Naturalist 112: 676-683.

ESRI ArcMap 9.0. 2004. ESRI Inc., Redlands, CA.

ESRI 3D Analyst 9.0. 2004. ESRI Inc., Redlands, CA.

Gaston, A.J. 1990. Population parameters of the Ancient Murrelet. Condor 92: 998-1011.

Gaston, A.J. 1992. The Ancient Murrelet: a natural history in the Queen Charlotte Islands. Poyser, London.

Gaston, A.J. 1994. Status of the Ancient Murrelet, *Synthliboramphus antiquus*, in Canada and the effects of introduced predators. Canadian Field-Naturalist 108: 211-222.

Harfenist, A. 1994. Effects of introduced rats on nesting seabirds of Haida Gwaii. Technical Report Series No. 218. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

Harris, M.P. 1983. Biology and survival of the immature puffin Fratercula arctica. Ibis 125: 56-73.

Harris, M.P. 1984. The puffin. T & AD Poyser, Calton.

Hartman, L.H. and D.S. Eastman. 1999. Distribution of introduced raccoons *Procyon lotor* on the Queen Charlotte Islands: implications for borrow-nesting seabirds. Biological Conservation 88: 1-13.

Hipfner, J.M., D.F. Bertram and K.H. Morgan. 2002. Pacific & Yukon regional Seabird Conservation Plan. PYR Delta.

Hobson K.A., M.C. Drever and G.W. Kaiser. 1999. Norway rats as predators of burrow-nesting seabirds: Insights from stable isotope analysis. Journal of Wildlife Management 63: 14-25.

Hudson, P.J. 1985. Population parameters for the Atlantic Alcidae. Pp. 233-261 *in* D.N. Nettleship and T.R. Birkhead. The Atlantic Alcidae. Academic Press, London.

Kaiser, G.W., R.H. Taylor, P.D. Buck, J.E. Elliott, G.R. Howald and M.C. Drever.1997. The Langara Island Seabird Habitat Recovery Project: Eradication of Norway rats – 1993-1997. Technical Report Series No. 304. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

Lemon, M.J.F. 1993. Survey of Ancient Murrelet colony at Dodge Point on Lyell Island in 1992. Pp. 38-51 *in* A.J. Gaston and A. Lawrence (Eds.). Laskeek Bay Conservation Society Report on Scientific Activities # 3, 1992.

Moors, P.J. and I.A.E. Atkinson. 1984. Predation on seabirds by introduced animals, and factors affecting its severity. Pp. 667-690 *in* J.P. Croxall, P.G.H. Evans and R.W. Schreiber (Eds.). Status and conservation of the world's seabirds. ICBP Technical Publication No. 2.

Nelson, R.W. 1990. Status of the Peregrine Falcon, *Falco peregrinus pealei*, on Langara Island, Queen Charlotte Islands, British Columbia, 1968-1989. Canadian Field-Naturalist 104: 193-199.

Pearce, R.L., J.J. Wood, Y. Artukhin, T.P. Birt, M. Damus and V.L. Friesen. 2002. Mitochondrial DNA suggests high gene flow in Ancient Murrelets. Condor 104: 84-91.

Rodway, M. S. 1991. Status and conservation of breeding seabirds in British Columbia. Pp. 43-102 *in* J.P. Croxall (Ed.). Seabird status and conservation: a supplement. ICBP Technical Publication No. 11.

Rodway, M.S., N. Hillis and L. Langley. 1983. Nesting population of Ancient Murrelets on Langara Island, British Columbia. Technical Report. Canadian Wildlife Service, Delta, British Columbia.

Rodway, M.S., M.J.F. Lemon and G.W Kaiser. 1988. British Columbia Seabird Colony Inventory: Report #1 – East Coast Moresby Island. Technical Report Series No. 50. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

Rodway, M.S., M.J.F. Lemon and G.W Kaiser. 1994. British Columbia Seabird Colony Inventory: Report #6 – Major colonies on the west coast of Graham Island. Technical Report Series No. 95. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

Sealy, S.G. 1976. Biology of nesting Ancient Murrelets. Condor 78: 294-306.

Taylor, R.H., G.W. Kaiser and M.C. Drever. 2000. Eradication of Norway rats for recovery of seabird habitat on Langara Island, British Columbia. Restoration Ecology 8: 151-160.

Thibault, J.C. 1995. Effect of predation by the black rat *Rattus rattus* on the breeding success of Cory's Shearwater *Calonectris diomedea* in Corsica. Marine Ornithology 23: 1-10.

Towns, D.R. and K.G. Broome. 2003. From small Maria to massive Campbell: Forty years of rat eradications from New Zealand islands. New Zealand Journal of Zoology 30: 377-398.

Table 1. Standardized numbering system used for the 32 transects surveyed in 2004 and the corresponding labels used previously for the same transects surveyed in studies conducted between 1981 and 2004. Transects surveyed in previous years at different locations than in 2004 are not listed. Transects are listed clockwise around Langara Island from W to SE (Fig. 2). Active transects are indicated with asterisks.

Transect label	1981[1]	1988[2]	1993[3]	1999[4]	2004[5]
1		12	12[6]	12	12
2	3	11	11[6]	11	11
3				J	J
4		10*	10	Z	Z
5					42a
6			J	42	42
7					10*
8			I*	10*	9*
9	4*	9*	9*	9*	K*
10			K*	K*	R*
11			P*	R*	N*
12			N*	N*	O*
13			O*	O*	3*
14	5*	3*	H*	3*	H*
15				H*	2*
16			G*	G*	G*
17		2*	2*	2*	F*
18			F*	F*	E*
19	6*	1*	1*	1	1*
20		14	14	14*	14*
21				13*	13a*
22		13	13		13*
23			A	A*	A*
24	7*	4*	4*	4*	4*
25			D*	D*	D*
26			C*[6]	C*[6]	C*
27			B*	B	B
28		5	L	L	L
29	8*	7	7	7	7
30		8	8	8	8
31	9*	16	16	16	16
32	10*	15	15	15	15

[1] from Rodway *et al.* (1983, 1994).
[2] from Bertram (1989).
[3] from Harfenist (1994).
[4] see Appendix 1 and Drever (2002).
[5] these labels were used to mark transects in the field in 2004 based on labels used in previous years.
[6] transect in slightly different location than in 2004.

Table 2. Extent of Ancient Murrelet colony for each active transect (Fig. 2) on Langara Island, 2004.

Transect	Shore colony boundary (m from shore)	Interior colony boundary (m from shore)	Colony width (m)
7	60	100	40
8	0	220	220
9	0	220	220
10	20	260	240
11	0	300	300
12	0	180	180
13	20	300	280
14	20	220	200
15	0	220	220
16	0	260	260
17	0	300	300
18	0	260	260
19	0	140	140
20	20	140	120
21[1]	180	-	-
22[1]	180	-	-
23	20	220	160
24	0	180	180
25	0	140	140
26	20	100	80

[1]transect runs parallel to shore and perpendicular to transects on the north shore (Fig. 2).

Table 3. Numbers of Ancient Murrelet burrows in 5 x 5 m quadrats and total quadrats within the active colony for each transect surveyed on Langara Island in 2004 (Fig. 2). Quadrats outside of the active colony are indicated with a dash; quadrats that were not surveyed because transects had ended are left blank. Quadrats were placed 40 m apart along transects beginning at the vegetation edge at shore.

Transect	Number of burrows in quadrat									Total quadrats in colony
	1	2	3	4	5	6	7	8	9	
7	-	-	0	-	-					1
8	0	0	0	5	1	0	-			6
9	6	1	1	1	2	0	-	-		6
10	-	3	0	0	3	1	0	-		6
11	4	0	1	2	7	0	1	0	-	8
12	0	9	1	0	0	-				5
13	-	0	4	1	0	3	3	1	-	7
14	-	2	2	1	3	0	-			5
15	2	1	1	1	2	1	-			6
16	8	2	0	3	0	3	0	-		7
17	3	4	1	9	5	0	0	0	-	8
18	2	0	1	2	1	0	0	-		7
19	2	0	3	1	-	-				4
20	-	0	1	1	-					3
21	-	-	-	-	-	1				1
22	-	-	-	-	-	3				1
23	-	0	-	0	1	0	-			4
24	2	0	1	0	1	-				5
25	0	3	8	0	-	-				4
26	-	1	0	-	-					2

Table 4. Comparison of colony area, number of quadrats within the active colony, burrow density, total numbers of burrows, occupancy rate, and estimated breeding population, for the main Ancient Murrelet colony on Langara Island from 1981 to 2004.

Year	Colony area (ha)	Number of quadrats	Mean burrow density ± SE (burrows/ha)	Total number of burrows	Occupancy rate (%) ± SE	Breeding population (pairs)
1981[1]	116.6	39	820 ± 139	95,612 ± 16,207	26.3 ± 8.0	25,146 ± 8,660[5]
1988[1]	45.6	31	1,358 ± 225	61,925 ± 10,260	38.4 ± 7.7	23,779 ± 6,149[6]
1993[2]	28.5	59	1,800 ± 160	51,318 ± 4,562	35.5 ± 3.9	18,214 ± 2,565[7]
1999[3]	44.7	68	765 ± 104	34,195 ± 4,649	39.2 ± 5.5	13,014 ± 2,525
2004[4]	61.1	96	625 ± 85	38,176 ± 5,192	63.0 ± 6.4	24,037 ± 4,073

[1] from Rodway *et al.* (1994).
[2] from Harfenist (1994) with revised colony area, total number of burrows, and breeding population (see methods).
[3] from Drever (2002) with revised colony area, total number of burrows, and breeding population (see methods).
[4] this study.
[5] an additional 550 pairs estimated for Iphigenia Point and Fury Bay (Fig. 1).
[6] an additional 280 pairs estimated for Cohoe Point.
[7] an additional 25-50 pairs estimated for Cohoe Point.

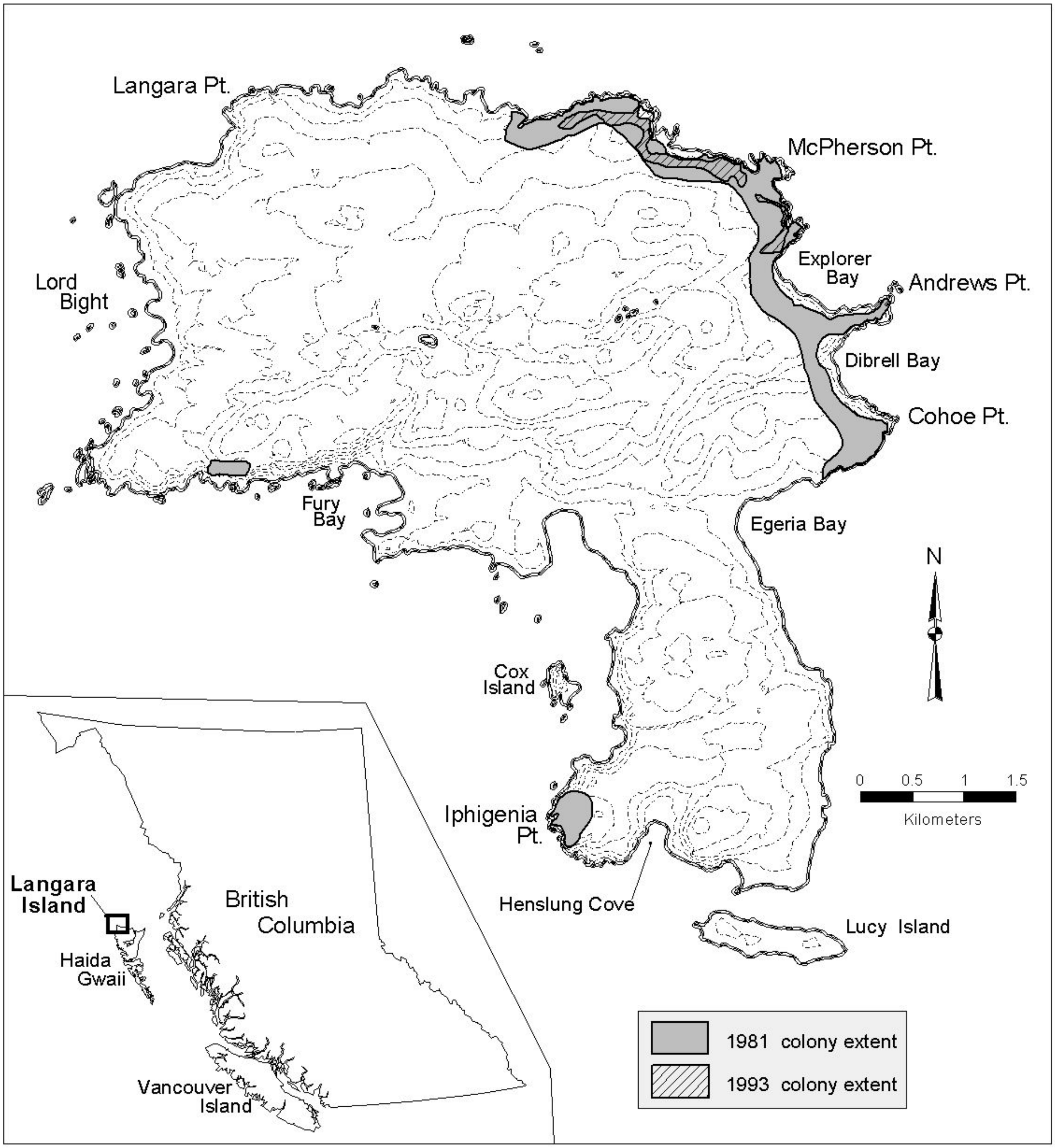

Figure 1. Contraction of the Ancient Murrelet colony area on Langara Island from 1981 to 1993 prior to the eradication of rats. Note that a small remnant of active colony was found on the north side of Cohoe Pt. in 1993 that was too small to map on this figure.

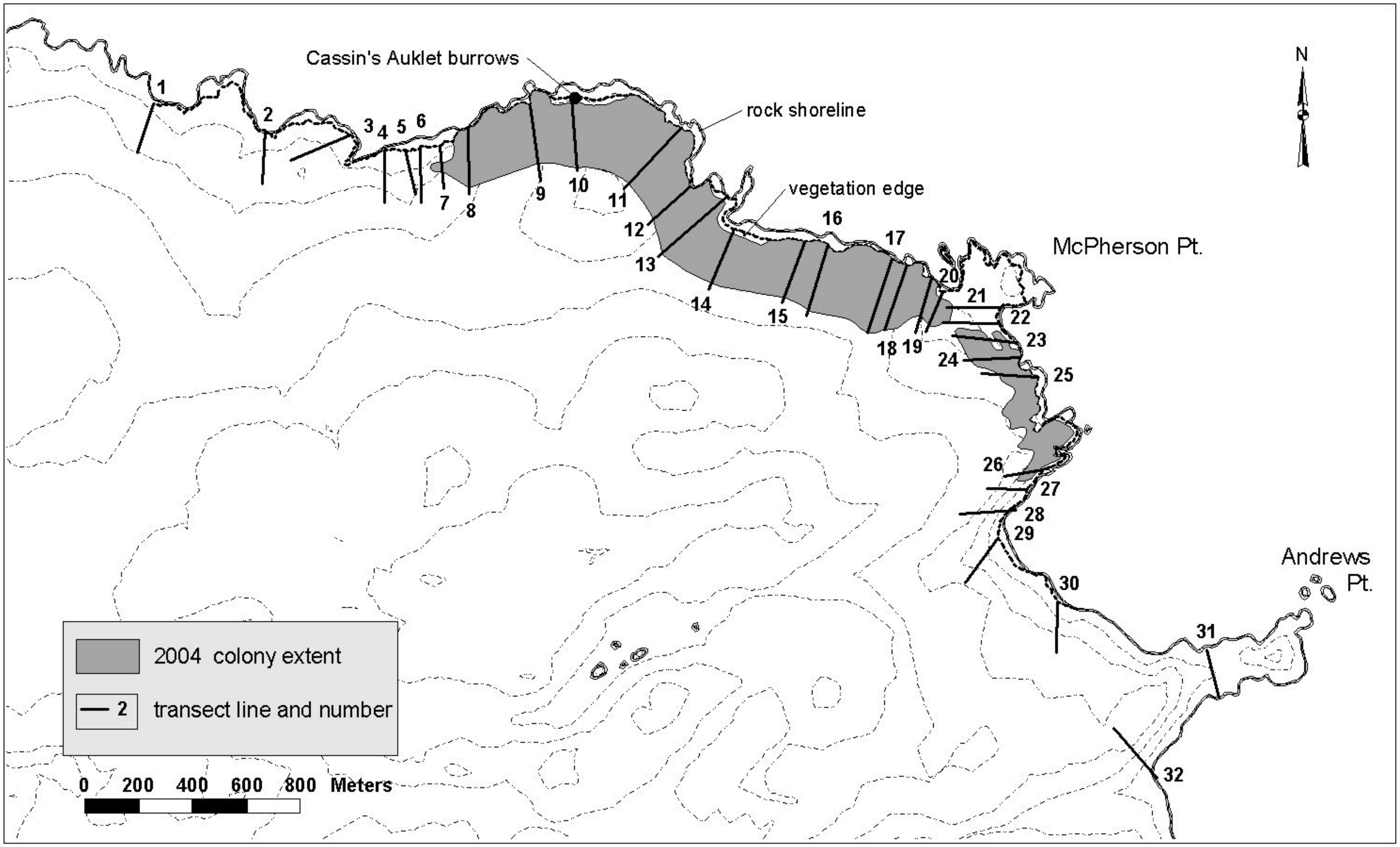

Figure 2. Location of transects and extent of Ancient Murrelet colony on Langara Island in 2004. Location of a small pocket of Cassin's Auklet burrows discovered in 2004 is also indicated.

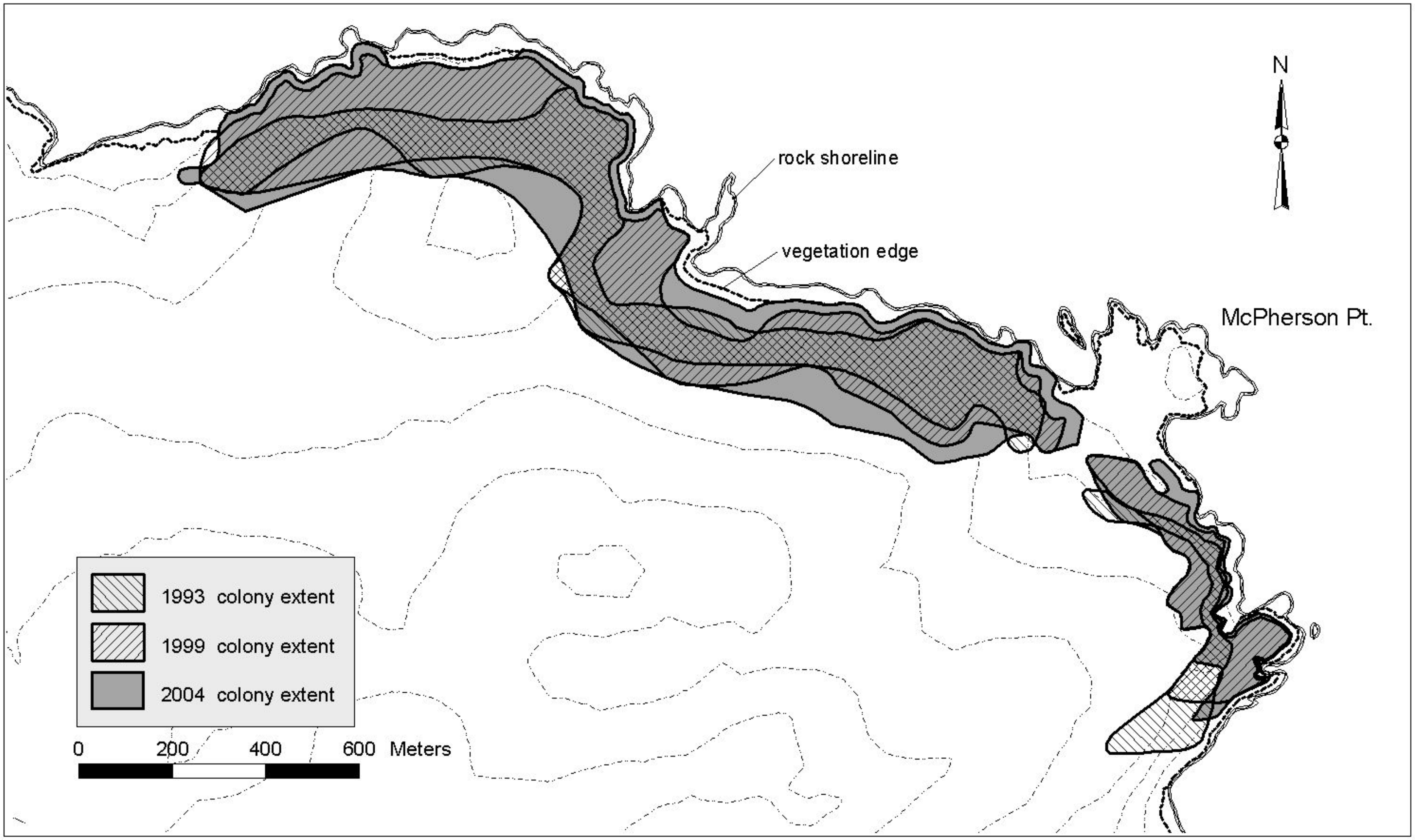

Figure 3. Comparison of the main Ancient Murrelet colony area in the vicinity of McPherson Point on Langara Island in 1993, 1999, and 2004. Fill patterns overlap where colony was present in more than one year.

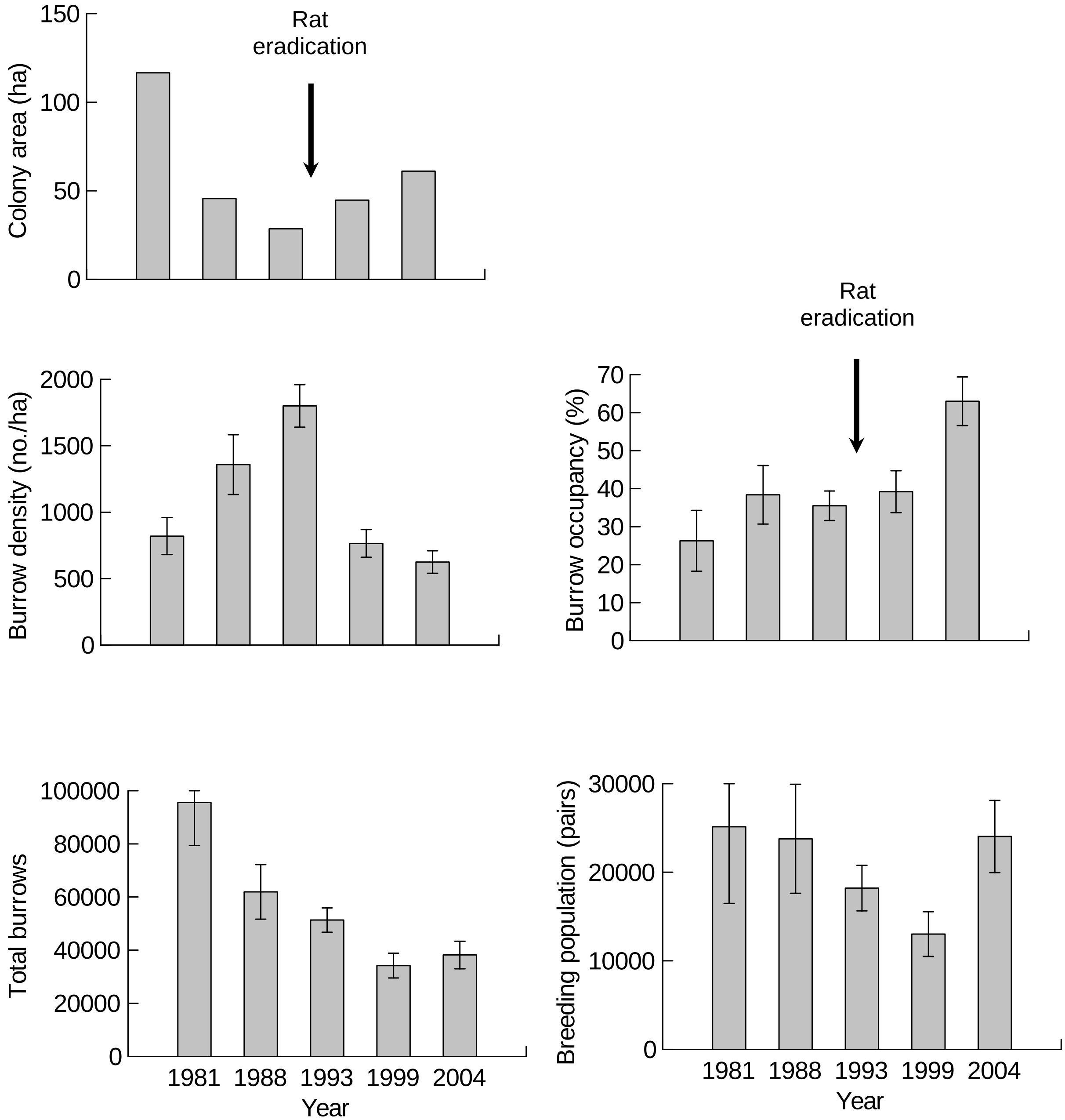

Figure 4. Changes in component measures used to estimate breeding populations of Ancient Murrelets on Langara Island before and after the eradication of Norway rats.

Appendix 1. Locations of transects surveyed in 1999. Figure is revised from Fig. 2 in Drever (2002) and was provided by M. Drever.

Appendix 2. Locations and characteristics of all transects (active and inactive) used in the survey of Ancient Murrelets on Langara Island in 2004 including compass bearing, total length surveyed, total number of quadrats, and the latitude and longitude of the shore (S) and interior (I) reference points taken by GPS to locate transect end points. Transects are listed clockwise around Langara Island from W to SE (Fig. 2). Footnotes show distance and bearing to transect end points from GPS reference points when reference points were > 10 m from transect end points.

Transect	Compass bearing (°)	Transect length (m)	Number of quadrats	GPS reference point	Latitude	Longitude
1	202	205	6	S	54.25570	133.02842
				I	54.25410	133.02940
2	190	205	6	S	54.25472	133.02212
				I	54.25295	133.02239
3	260	245	7	S	54.25449	133.01730
				I	54.25372	133.02072
4	180	200	5	S	54.25396	133.01541
				I[1]	54.25221	133.01550
5	180	183	5	S	54.25395	133.01422
				I	54.25246	133.01373
6	180	165	5	S	54.25403	133.01335
				I[2]	54.25219	133.01341
7	180	165	5	S	54.25403	133.01223
				I[3]	54.25231	133.01205
8	180	245	7	S	54.25460	133.01062
				I[4]	54.25226	133.01067
9	180	285	8	S	54.25531	133.00705
				I	54.25280	133.00660
10	180	285	8	S	54.25555	133.00469
				I	54.25305	133.00448
11	230	325	9	S	54.25443	132.99853
				I[5]	54.25229	133.00218
12	230	205	6	S	54.25246	132.99814
				I	54.25126	133.00057
13	230	325	9	S	54.25211	132.99603
				I[6]	54.25010	133.00002
14	200	245	7	S	54.25102	132.99568
				I	54.24905	132.99722
15	200	245	7	S[7]	54.25052	132.99174
16	200	285	8	S[7]	54.25042	132.99039
17	200	305	9	S[7]	54.24992	132.98677

Appendix 2. cont.

Transect	Compass bearing (°)	Transect length (m)	Number of quadrats	GPS reference point	Latitude	Longitude
18	200	285	8	S[7]	54.24966	132.98592
19	200	205	6	S	54.24922	132.98458
				I	54.24743	132.98559
20	204	165	5	S	54.24873	132.98398
				I	54.24745	132.98498
21	270	205	6	S	54.24819	132.98066
22	270	205	6	S	54.24766	132.98086
23	270	245	7	S	54.24700	132.98000
				I	54.24727	132.98350
24	270	205	6	S	54.24649	132.97971
				I	54.24646	132.98291
25	270	205	6	S	54.24583	132.97868
				I	54.24601	132.98190
26	270	165	5	S	54.24276	132.97856
				I	54.24259	132.98079
27	270	165	5	S	54.24215	132.97950
				I	54.24221	132.98180
28	270	205	6	S	54.24145	132.98015
				I	54.24138	132.98338
29	225	205	6	S	54.24057	132.98120
				I	54.23909	132.98316
30	185	205	6	S	54.23838	132.97796
				I	54.23671	132.97811
31	343	183	5	S	54.23504	132.96896
				I	54.23665	132.96957
32	315	205	6	S	54.23247	132.97260
				I	54.23414	132.97501

[1] interior transect end is 35 m @ 0° from GPS reference point.
[2] interior transect end is 25 m @ 0° from GPS reference point.
[3] interior transect end is 37 m @ 0° from GPS reference point.
[4] interior transect end is 17 m @ 0° from GPS reference point.
[5] interior transect end is 27 m @ 50° from GPS reference point.
[6] interior transect end is 11 m @ 340° from GPS reference point.
[7] usable GPS reference point for the interior end of transect was not obtained.

Appendix 3. Description of the shore ends of transects, and distance and bearing from the start of the transect to the marker tree (metal tags on trees have 2004 field labels, see Table 1), for each transect used in the survey of Ancient Murrelets on Langara Island in 2004. Transects are listed clockwise around Langara Island from W to SE (Fig. 2).

Transect	Description of transect start location	Location of marker tree
1	large bent spruce tree E of creek near sandy beach	2 m @ 166°
2	~30 m E of creek beside rocky beach; bearing 38° to centre of eastern Langara Rocks; spruce with dbh of 1 m	3 m @ 170°
3	beside large spruce tree; bearing 18° to E-most Langara Rocks	7.5 m @ 13°
4	grassy bluff jutting out between rocky shoreline to the E and the W, just E of narrow tidal bay; bearing 5° to E-most Langara Rock	1 m @ 234° (inside first quadrat)
5	open mossy ridge top, ridge is E of creek; there is another gully to the E of transect start; 250 m from transect 8 start	6 m @ 248°
6	grassy and mossy bluff with a lightly forested bluffy island to the NW, separated by a rocky tidal channel; bearing 350° to E-most Langara Rock; 130 m, 50-70 m, 80-100 m, 210 m, and 460 m from transects 4, 5, 7, 8, and 9, respectively	4 m @ 252°
7	rocky shore with small grass gully and large fallen spruce	10.5 m @ 167°
8	grassy outcrop ~50 m E of long, narrow, tidal gully; large spruce close to shore (this is the marker tree); bearing 338° to E-most Langara Rock	2.2 m @ 292°
9	260 m from start of transect 8	6 m @ 190°
10	SE of steep-sided tidal gully; gully is SE of large rock jut visible on air photo; 400 m from transect 8 start	7 m @ 160°
11[1]	rocky steep sided point; dense spruce trees	6 m @ 310° 2 m @ 50°
12	base of steep slope on W side of small bay; slope is surrounded by bluffs; 140 m from transect 13 start	4 m @ 209°
13	~10 m W of narrow tidal gully running north-south along W side of prominent finger of rock; grassy knoll with narrow tidal gullys to the E and W	8 m @ 230°
14	E side of beach that is at the base and to the E of prominent finger of rock; 100 and 260 m from start of transects 13 and 15, respectively	3.2 m @ 156°
15	grassy knoll projecting out between rocky shelves to the E and the W; tip of McPherson Pt. is visible to the E	7 m @ 200°
16	grassy hillside with many hummocks; 90 m from transect 15 start	6 m @ 250°

Appendix 3. cont.

Transect	Description of transect start location	Location of marker tree
17	70 m from transect 18 start	4 m @ 200°
18	forested outcrop W of bay W of McPherson Pt., with a large rock jut to the N that runs in a NE direction and is clearly visible on air photo; narrow boulder bays on either side; bearing 70° to island in Bay W of McPherson Pt.	7 m @ 200°
19	first projecting knoll on W side of Bay W of McPherson Pt.; 100 m from transect 18 start	4.5 m @ 220°
20	W end of small rocky beach with open mature spruce forest to the south; 160 m from transect 18 start	5 m @ 195°
21	beach S of McPherson Pt., ~halfway between rock outcrops to the N and S of cobble beach, 16 m along the vegetation line from the northern rock outcrop	none
22	close to S end of cobble beach S of McPherson Pt.; 60 m from N end of beach	25 m @ 251°
23	S side of camp S of McPherson Pt. (bearing 345° to camp); grassy spot between two rocky points on shoreline	6 m @ 110°
24	top of hill W of small beach between two rock points; grassy opening surrounded by large spruce	6 m @ 312°
25	exposed grassy hillside with medium sized spruce; bearing 125° to Andrews Pt. and 15° to McPherson Pt.	5 m @ 110°
26	beginning of grass at top end of a distinct gorge in the rocky shoreline; 180 m from transect 28 start	8.7 m @ 272°
27	bottom of steep gully with grass and large spruce	8 m @ 312°
28	60 m NE of bend in beach in northern half of Explorer Bay; rock boulders of beach increase to 6-8 feet in diameter; tall rock pinnacle 43 m to the N along the shore	0 m
29	middle of NE-facing beach in Explorer Bay; ~15 m N of main flowing creek channel and ~5 m N of most northerly branch of creek seepage area; 120 m from transect 28 start	0 m
30	southern Explorer Bay at NE-facing section of beach, approx. midway between two small rocky points; patch of grass tussocks above cobble beach	13 m @ 220°
31	across point from Dibrell Bay into Explorer Bay; small forested jut in shoreline; boulder beach ends ~30 m to SW	2 m @ 250°
32	Dibrell Bay, at S end of W-facing short (~30 m long) gravel beach, 8 m north of creek; large upturned tree with roots on beach and trunk on shore, some of trunk in first quadrat	8 m @ 167°

[1] two tag trees used because of dense vegetation, first has 2 tags, second has 1 tag.

Appendix 4. Evidence of Ancient Murrelet predation found in 5 m strip between quadrats along transects surveyed on Langara Island in 2004. Transects are listed clockwise around Langara Island from W to SE (see Fig. 2). Signs of predation within quadrats are not included (these are reported in Appendix 5).

Transect	Feather pile	Depredated eggshells	Pellet	Pair of wings	Single wing	Carcass
1	0	0	0	0	0	0
2	0	0	1	0	0	0
3	0	0	0	0	0	0
4	2	0	0	0	0	0
5	2	0	0	0	0	0
6	0	0	0	0	3	0
7	1	1	0	0	0	0
8	1	1	1	0	0	0
9	4	3	0	1	0	0
10	4	1	0	0	0	0
11	7	1	0	0	1	1
12	7	4	2	0	0	0
13	14	5	1	0	0	0
14	5	5	0	0	0	0
15	9	2	2	0	0	0
16	11	0	1	0	0	0
17	7	1	2	0	0	0
18	5	3	2	0	0	0
19	2	0	2	0	0	0
20	3	0	0	0	0	0
21	2	0	0	0	0	0
22	1	0	0	0	1	0
23	0	1	0	0	0	0
24	2	1	0	0	0	0
25	2	3	1	0	0	0
26	1	0	0	0	0	0
27	0	0	0	0	0	0
28	0	0	0	0	1	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	0	0	0	0	0	0
32	0	0	0	0	0	0

Appendix 5. Characteristics of all quadrats (active and inactive) and Ancient Murrelet and Cassin's Auklet burrows surveyed on Langara Island in 2004. Transects are listed clockwise around Langara Island from W to SE (see Fig. 2). Cassin's Auklet burrows were found only on transect 10 in the first quadrat and are listed at the end of the appendix.

Transect	Quadrat	Slope (°)	Signs of predation in quadrat[1]	Burrow No.	Burrow Entrance[2]	Signs at entrance[3]	Burrow content[4]	Burrow length (cm)[5]
Ancient Murrelet								
1	1	12	0					
	2	3	0					
	3	10	0					
	4	35	0					
	5	1	0					
	6	3	0					
2	1	11	0					
	2	16	0					
	3	18	0					
	4	1	0					
	5	5	0					
	6	-3	0					
3	1	6	0					
	2	26	0					
	3	0	0					
	4	-2	0					
	5	5	0					
	6	6	0					
	7	10	1 fp					
4	1	5	0					
	2	0	0					
	3	45	0					
	4	17	0					
	5	17	0					
5	1	6	0					
	2	20	0	1	2a	k	em, k	70 r
	3	20	0					
	4	11	0					
	5	1	0					
6	1	23	0					
	2	41	0					
	3	22	0					
	4	8	0					
	5	20	ef, fp					
7	1	13	0					
	2	22	0					
	3	3	0					
	4	5	0					
	5	22	0					

Appendix 5, cont…

Transect	Quadrat	Slope (°)	Signs of predation in quadrat[1]	Burrow No.	Burrow entrance[2]	Signs at entrance[3]	Burrow content[4]	Burrow length (cm)[5]
8	1	5	0					
	2	-5	0					
	3	20	0					
	4	43	0	1	9b	k	eh, k	>60
				2	9b	k	eh, k	60 r
				3	9b	k	eh, em	60 r
				4	9b	k	f,k,emp	90 d
				5	9b	k	eh, ce, k	>60
	5	6	1 pel	1	5a	d	unk	>100 d
	6	5	0					
	7	4	0					
9	1	30	0	1	9a	em, k	gr, unk	>80
				2	9a	k	k, unk	>60
				3	9a	k	k, unk	>100
				4	9a	eh, f	emp	60 r
				5	9a	f,k	unk	>70
				6	9a	k,d	k, unk	>100
	2	35	0	1	5a	k	eh, em	>60
	3	17	1 fp	1	2a	d,k	k, unk	>100
	4	10	0	1	5a	k	em, k	70 r
	5	10	0	1	2a	k, d	em, k	75 r
				2	2a	k	unk	>60
	6	-2	0					
	7	0	0					
	8	17	0					
10	1	34	1 fp CA					
	2	-4	1 fp CA	1	7a	eh, k	eh	>60
				2	9b	k	unk	>40
				3	5a	k	eh	>60
	3	43	0					
	4	-1	0					
	5	5	1 ep	1	8a	k	gr, unk	>100 d
				2	3a	k	eh, em	>60
				3	2a	d,f	unk	>60
	6	14	0	1	9a	k	f, unk	>40
	7	8	0					
	8	-12	0					
11	1	40	1 fp	1	2,3a	k,f	k,f,em	>50
				2	2a	k	unk	>60
				3	2a	k	unk	>50
				4	2a	k	k,em,eh	>60
	2	18	0					
	3	31	1 w	1	4a	k	eh, em	>60
	4	25	0	1	2,4a	k,d	em, k	50 r
				2	2,4a	k	k, 1 ce	50 r

Appendix 5, cont..

Transect	Quadrat	Slope (°)	Signs of predation in quadrat[1]	Burrow No.	Burrow entrance[2]	Signs at entrance[3]	Burrow content[4]	Burrow length (cm)[5]
11	5	-10	1 fp	1	2a	k,em,f	eh, k, em	30 r
				2	6a	k,f	eh, k, em	>40
				3	2,9a	k,em,f,d	eh, k, em	>40
				4	2a	k,f,d	eh	>60
				5	6,9a	k,d	em, unk	>100
				6	2a	k	em	40 r
				7	6,9a	eh, k,d	eh, em	40 r
	6	7	0					
	7	16	0	1	5a	k	em,gr,k	50 r
	8	0	0					
	9	13	0					
12	1	16	0					
	2	42	0	1	9a	d,f	k, unk	>60
				2	9a	d,f	unk	>60
				3	2c	d	f, unk	>30
				4	9a	f	em	30 r
				5	2,3a	d,f	eh	>60
				6	5a		eh, f	>30
				7	6a	d,k	nc, unk	>60
				8	4a	d	unk	>60
				9	9a	d,f	unk	>60
	3	29	0	1	5a	k	nc, unk	>60 d
	4	0	1 ich					
	5	-3	1 ep					
	6	8	0					
13	1	3	0					
	2	10	0					
	3	0	0	1	9b	ef	ef, nc, unk	>60
				2	5b	k	eh, em	50 r
				3	5b		eh, em	60 r
				4	3a	d	epc	40 r
	4	12	0	1	2b	d	eh, f	>60
	5	0	1 fp					
	6	35	1 fp	1	9a	k	unk	>30
				2	5a	ef	eh	>60
				3	4a	em	unk	>40
	7	10	1 fp	1	2a		k, unk	>60
				2	2a	f, k	eh, em	>60
				3	5a		eh, 1 ce	120 d
	8	5	1 ep	1	2a	f	epc, em	>60
	9	0	0					
14	1	9	1 fp					
	2	16	1 fp	1	2a	k	eh, k, gr, em	60 r
				2	2a	eh, k	eh, k	60 r
	3	28	0	1	2a	k	k, em	50 r
				2	2a	k	unk	> 70

Appendix 5, cont…

Transect	Quadrat	Slope (°)	Signs of predation in quadrat[1]	Burrow No.	Burrow entrance[2]	Signs at entrance[3]	Burrow content[4]	Burrow length (cm)[5]
14	4	17	0	1	3a	k	eh, em, k	150 d
	5	5	0	1	1b	eh, k	unk	>30
				2	1,3a	eh, k, f	unk	>40
				3	1a	k	eh, k	>30
	6	5	0					
	7	8	0					
15	1	-4	0	1	3b	eh, k	eh, em,k,gr	50 r
				2	9a	d,k	eh, em,k,gr	50 r
	2	15	0	1	9a	k	k,nc,unk	>60
	3	15	1 ep	1	5c	k,d	ef,em,unk	>60
	4	12	1 fp	1	5a	k	k, unk	>60
	5	15	1 fp	1	5b	k	unk	>60
				2	2a	k	eh	>60
	6	5	0	1	5a	k	eh, em, k	>50
	7	10	0					
16	1	21	0	1	6a	k	eh, f, k	25 r
				2	6a	k	em, k	100 r
				3	7a	k	eh, em	>50
				4	7b	k	eh, em	>30
				5	6a	k	k, unk	>60
				6	7a	k	k, w	>60
				7	6a	k	eh, k,d	>70
				8	6a	k	eh, k	>70
	2	-1	0	1	2,4a	k,d	em, unk	>50
				2	4b	k,d,f	unk	>60
	3	19	0					
	4	11	0	1	4a	k	eh, gr	90 r
				2	4a	k	em,gr, unk	75 r
				3	4a	k	em, unk	70 r
	5	17	0					
	6	12	0	1	2a	d,k	eh, gr, em	>60
				2	5a	d,k	eh, gr, em	90 r
				3	2a	d,k	eh, gr, em	>70
	7	12	0					
	8	14	0					
17	1	37	1 fp	1	9a	k	eh	60 r
				2	7,9a	k	eh	50 r
				3	7,9a	k	k,unk	>100
	2	-7	1 fp, 2 pel	1	5a	k	eh, em	60 r
				2	5a	k,d	k, unk	>100 d
				3	5a	k,d	k, unk	>100
				4	5a	k,d	k, gr, unk	>100
	3	23	0	1	5a	k	eh	20 r

Appendix 5, cont..

Transect	Quadrat	Slope (°)	Signs of predation in quadrat[1]	Burrow No.	Burrow entrance[2]	Signs at entrance[3]	Burrow content[4]	Burrow length (cm)[5]
17	4	22	1 ep, 1 w	1	4a	k	eh, em	50 r
				2	4a	k	emp	40 r
				3	2a	ef, k	eh	30 r
				4	4a	k	unk	>60
				5	4a	eh,k	eh	>100
				6	5a	k	k, unk	>70 d
				7	5a	k	k, unk	30 r
				8	4a	k	eh, em	80 r
				9	4a	k,f	k, unk	>70
	5	25	1 pel	1	2a	k	ce	70 r
	5			2	2a	k	em	60 r
				3	2a	k	k, unk	>100
				4	2a	k	emp	120 d
				5	2a	d	unk	>100 d
	6	5	0					
	7	21	1 w					
	8	0	0					
	9	0	0					
18	1	33	0	1	6,9a	f	k, unk	>60
				2	6a	k	k, unk	>60
	2	-22	0					
	3	20	1 ep	1	1a	d	k, emp	40 r
	4	13	0	1	2a		eh, em, gr	>60
				2	2,5a	d	em, unk	>60
	5	16	0	1	5a	d	em, unk	>60 d
	6	6	0					
	7	6	0					
	8	0	0					
19	1	17	0	1	4a	k	eh, k	>70
				2	2a	k	eh, em, f, k	70 r
	2	14	0					
	3	16	0	1	3a	k, d	eh, k	>60
				2	2a	k	eh, em, k	>60
				3	2a	k, d	eh, k	50 d
	4	13	0	1	4c	d, k	eh, d, k	>40
	5	16	0					
	6	4	0					
20	1	11	0					
	2	9	2 ep					
	3	9	1 fp	1	2a	k	k, em	60 r
	4	4	0	1	4a	k	k, em	60 d
	5	5	0					
21	1	9	0					
	2	0	0					
	3	2	0					
	4	-13	0					

Appendix 5, cont..

Transect	Quadrat	Slope (°)	Signs of predation in quadrat[1]	Burrow No.	Burrow entrance[2]	Signs at entrance[3]	Burrow content[4]	Burrow length (cm)[5]
21	5	-1	0					
	6	37	0	1	2c		2 ce	30 r
22	1	11	0					
	2	2	0					
	3	0	0					
	4	0	c (chick)					
	5	2	0					
	6	25	1 pel	1	9a		emp	40 r
				2	9a		emp, gr	50 r
				3	9a		em, unk	>120 d
23	1	9	0					
	2	10	0					
	3	55	0					
	4	5	0					
	5	-7	0	1	1a	f	unk	>60
	6	-7	0					
	7	5	0					
24	1	15	1 fp	1	1a	eh, d, k	eh, d, f, k	100 r
				2	2a	f	eh, em	>50
	2	16	0					
	3	19	0	1	2a	eh, k	eh, k	>75
	4	4	0					
	5	4	0	1	3a	k	eh, em, k	60 r
	6	-10	0					
25	1	25	0					
	2	18	1 fp	1	2b	f	eh	60 r
				2	2a	k	k, gr, emp	90 r
				3	5b	k	eh, k	>50
	3	49	0	1	5a	k	k, emp	50 r
				2	2a	eh, k, f	unk	>60
				3	4a	eh, k, f	eh	>100
				4	4a	eh, k, f	eh	>40
				5	4a	eh, f	eh	>30
				6	5a	k	k, em	50 r
				7	2a	k, d	eh, k	>30
				8	9a	k	eh, k	50 r
	4	13	0					
	5		1 fp					
	6	7	0					

Appendix 5. cont…

Transect	Quadrat	Slope (°)	Signs of predation in quadrat[1]	Burrow No.	Burrow entrance[2]	Signs at entrance[3]	Burrow content[4]	Burrow length (cm)[5]
26	1	22	1 fp, 1 pel					
	2	27	0	1	2a	f,k	eh, f,k	60 r
	3	3	0					
	4	10	0					
	5	8	0					
27	1	35	0					
	2	45	0					
	3	7	0	1	2a	k,d	k,em	>50
	4	6	0					
	5	4	0					
28	1	0	0					
	2	22	0					
	3	13	0					
	4	3	0					
	5	10	0					
	6	3	0					
29	1	3	0					
	2	3	0					
	3	0	0					
	4	-2	0					
	5	10	0					
	6	8	0					
30	1	0	0					
	2	4	0					
	3	42	0					
	4	5	0					
	5	5	0					
	6	3	0					
31	1	-2	0					
	2	10	0					
	3	0	0					
	4	-10	0					
	5	-8	0					
32	1	0	0					
	2	0	0					
	3	0	0					
	4	25	0					
	5	2	0					
	6	2	0					
Cassin's Auklet[6]								
10	1	34	1 fp CA	1	9a	d,k	pp, k	>60
				2	9a	d,k	k, unk	>60

Appendix 5, cont…

[1]Signs of predation in quadrat:

- fp - Ancient Murrelet feather pile
- fp CA- Cassin's Auklet feather pile
- pel - pellet
- ep - depredated eggshell
- ef - eggshell fragments
- w - wing
- c - carcass
- ich - carcass with only head inverted

[2]Burrow entrance: *Burrow location*

- 1 - under tree
- 2 - live tree roots
- 3 - under stump
- 4 - dead tree roots
- 5 - fallen tree or log
- 6 - rock
- 7 - grass tussock
- 9 - into bank

Entrance class

- a - open/clear approach
- b - open/obscure approach
- c - obstructed/clear approach

[3]Signs at entrance:

- d - fecal droppings
- ef - eggshell fragments
- eh - current year hatched eggshell membrane
- em - old eggshell membrane from a previous year
- f - feathers
- k - worn entrance

[4]Burrow content:

- d - fecal droppings
- eh - current year hatched eggshell membrane
- em - old eggshell membrane from a previous year
- f - feathers
- k - worn tunnel
- ce - cold egg
- nc - nest cup
- epc - depredated eggshell from current breeding season
- w - wing
- gr - fresh broken pieces of green vegetation
- emp - empty burrow
- unk - unknown

[5]Burrow length:

- > - burrow was longer than the given number of cm and the burrow end was not reached
- r - burrow end reached without digging hatches
- d - one or more hatches dug

[6]the only Cassin's Auklet burrows were found on transect 10 in quadrat 1 and in the vicinity.