

RECOVERY OF THE ANCIENT MURRELET *SYNTHLIBORAMPHUS ANTIQUUS* COLONY ON LANGARA ISLAND, BRITISH COLUMBIA, FOLLOWING ERADICATION OF INVASIVE RATS

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SUMMARY

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Ancient Murrelets *Synthliboramphus antiquus* were nearly extirpated, and five other burrow-nesting species were extirpated from Langara Island, British Columbia, following introduction of first Black Rats *Rattus rattus* and later Norway Rats *R. norvegicus*. Rats were eradicated in 1995. To document the apparent response of Ancient Murrelets to introduced rats and to their removal, we compared colony surveys on Langara Island before (1981, 1988, 1993) and after (1999, 2004) rat eradication. We used surveys on two other colonies with rats, and five without rats, as approximate controls. Colony area decreased and burrow density increased on Langara Island in the presence of rats. Four years after rat removal, those trends had reversed. By 2004, the Ancient Murrelet colony had expanded to twice its pre-eradication area (to 61 ha from 29 ha), but burrow density had decreased (to 625 burrows/ha from 1800 burrows/ha) such that the number of burrows in the colony (38 176 in 2004) did not increase noticeably. Overall, the estimated breeding population almost doubled between 1999 (13 014 ± 2525) and 2004 (24 037 ± 4073) primarily because of an increase in burrow occupancy relative to all previous surveys (to an average of 63% from 35%), and was similar to that in other rat-free colonies. Cassin's Auklets *Ptychoramphus aleuticus*, that also had been extirpated from the island by rats, recolonized the island following rat eradication. Comparison with other colonies with and without invasive rats corroborated our conclusion that the Ancient Murrelet colony was responding positively to a successful rat eradication, and that we are beginning to achieve our goal of restoring Langara Island as an important seabird breeding colony.

Key words: Ancient Murrelet, Cassin's Auklet, introduced predators, rat eradication, seabirds, colony recovery

INTRODUCTION

Introduced predators pose grave threats to colonial seabirds, and their removal can be an effective seabird conservation action (Burger & Gochfeld 1994, Boersma *et al.* 2002, Jouventin *et al.* 2003). Langara Island, in the Haida Gwaii archipelago, British Columbia, formerly supported an estimated 200 000 breeding pairs of Ancient Murrelets *Synthliboramphus antiquus*, and large populations of Fork-tailed *Oceanodroma furcata* and Leach's *O. leucorhoa* Storm-Petrels, Cassin's Auklet *Ptychoramphus aleuticus*, Rhinoceros Auklet *Cerorhinca monocerata* and Tufted Puffin *Fratercula cirrhata* (Rodway 1991, Gaston 1992). Seabird population declines were observed following the introduction of rats to the island. Black Rats *Rattus rattus* were introduced to the Queen Charlotte Islands early in the 20th century. They were first identified on Langara Island in 1946 and were replaced more recently by Norway Rats *R. norvegicus*, first identified in 1981 (Bertram & Nagorsen 1995). By 1988, five burrow-nesting seabird species had been extirpated from Langara Island, apparently as a result of rat infestation, and only 24 000 pairs of Ancient Murrelets remained (Rodway 1991, Bertram 1995, Bertram & Nagorsen 1995). This remnant population was further reduced to fewer than 20 000 pairs by 1993 (Harfenist 1994). Following success in eradicating rats from islands in New Zealand (Townes & Broome 2003), Langara Island was targeted for rat eradication. Langara Island was a good candidate because of its historical importance as a seabird colony, because a remnant colony

of Ancient Murrelets and nearby colonies of other species could facilitate recovery, and because the breeding habitat is ideal (Kaiser *et al.* 1997). Rat eradication took place in 1995 and was considered complete in January 1996 (Kaiser *et al.* 1997, Taylor *et al.* 2000). In 2004, nine years after the eradication of rats, we surveyed burrow-nesting seabirds on Langara Island to assess the current status and prognosis of this historically important Ancient Murrelet colony and to assess whether other seabird species had recolonized the island. Specifically, we compared colony characteristics (colony area, burrow density, number of burrows, burrow occupancy, breeding population) before (1981, 1988, 1993) and after (1999, 2004) rat eradication (1995). We also compiled population trend data on nearby colonies to control for potential regional population fluctuations that might provide alternative explanations for changes observed on Langara Island.

METHODS

Study area and timing

We surveyed the Ancient Murrelet colony on Langara Island (54°14'N, 133°W), on the northwest tip of Haida Gwaii (Fig. 1), from 15 to 27 June 2004, after the Ancient Murrelet breeding season ended. We surveyed only the northeast corner of the island, the only active area in 1999. However, we explored the area around Cohoe Point, which had been active in 1981 (Rodway *et al.* 1994, Fig. 1), and where a remaining pocket of activity had been found

in 1988 (Bertram 1989) and 1993 (Harfenist 1994), but not in 1999 (Drever 2002). We searched for signs of nesting by other seabird species in all locations visited.

Survey methodology

Surveys were conducted using methods for “line transects with quadrats” as in previous years (Rodway *et al.* 1994, Bertram 1995). Transects were laid out perpendicular to shore, beginning

at the vegetation edge and ending beyond any nesting activity. Quadrats (5×5 m in size; $n = 196$) were laid out at 40-m intervals on the right side of transects. We replicated 30 transects that had previously been set up and had been surveyed in 1999, and we added two new transects (see Regehr *et al.* 2006 for greater detail concerning survey methods). We recorded transect start and end points using portable global positioning system (GPS) units. All GPS coordinates corresponded well with known points plotted

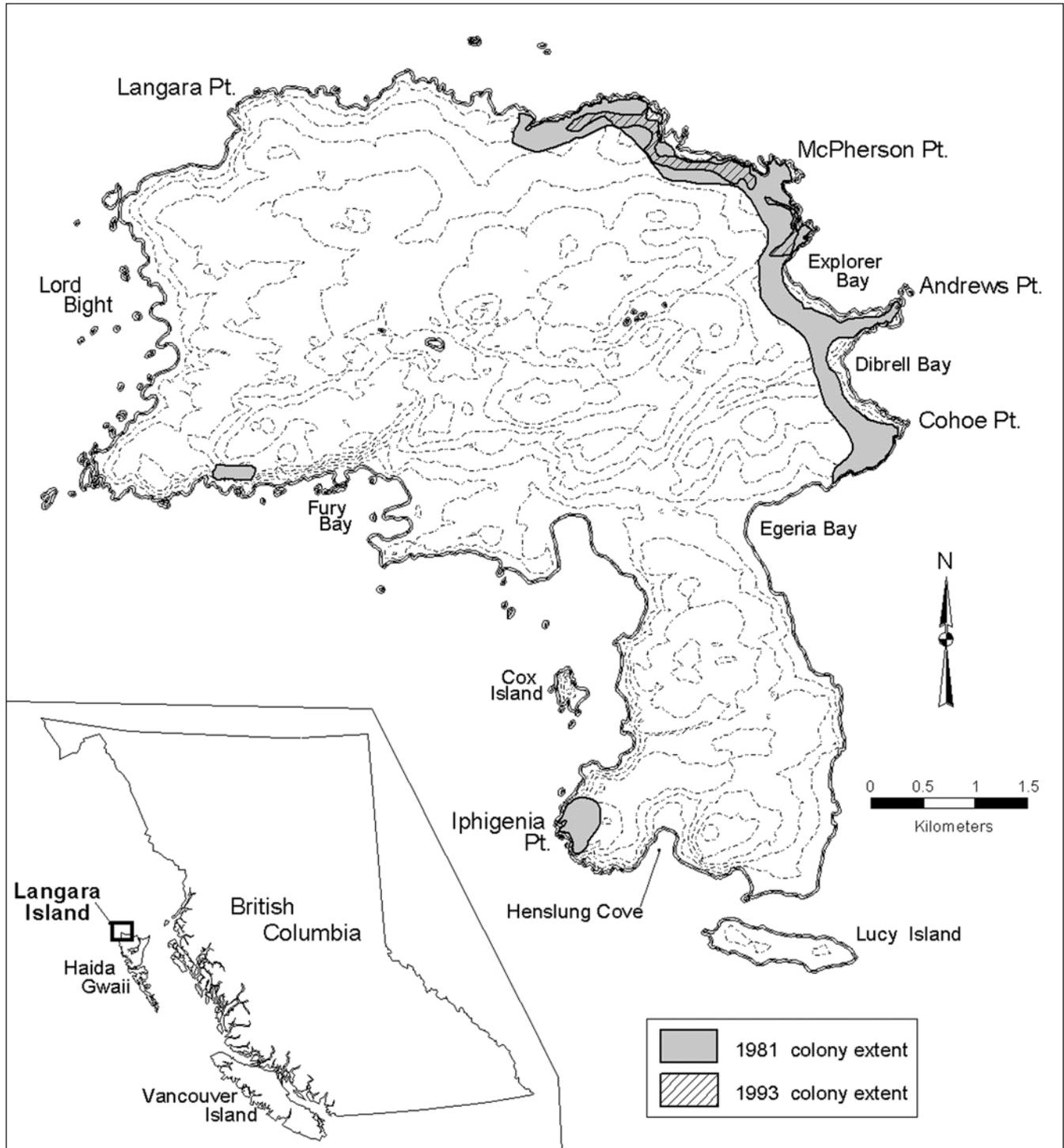


Fig. 1. Contraction of the Ancient Murrelet *Synthliboramphus antiquus* colony area on Langara Island from 1981 (Rodway *et al.* 1994) to 1993 (Harfenist 1994) before the eradication of rats. Note that a pocket of active colony on the north side of Cohoe Point in 1993 was too small to map.

on 1:12 500 air photos, indicating that GPS measurements were reliable. To record changes in topography, we measured slope with a clinometer at each quadrat and wherever slope changed noticeably along the transect line.

We distinguished between active and inactive quadrats to determine colony boundaries. Quadrats were defined as “active” if one or more burrows having signs of activity, such as worn tunnels, nesting materials or fecal material (but not necessarily signs of breeding, see later), were found within it or were encountered on the transect less than halfway to an adjacent quadrat (Rodway *et al.* 1994). We searched for burrows inside a 5-m strip on the right side of each transect, and as we approached the colony boundary toward the island interior, we also searched more widely for burrows on either side of the transect line until we felt confident that we were outside of the colony. These methods were designed to survey Ancient Murrelets that nest at low densities and with indistinct colony boundaries (Rodway *et al.* 1994).

Within each quadrat, we counted burrows and recorded information on their contents to indicate which had been used for breeding in that year. A burrow was considered “occupied” in the current breeding season if we were able to reach the end and found fresh eggshell membranes (white and flexible) or cold eggs, and “unoccupied” if we reached the end and found neither. We attempted to search each burrow completely and excavated hatches into tunnels (later patched to maintain integrity) when possible. Thus “occupancy rate” was defined as the percentage of burrows that could be completely

searched in which a breeding attempt resulting in egg production had been detected. We assumed that occupancy rates did not differ between burrows with ends we could reach and those we could not.

Colony mapping and estimation of colony statistics

Colony boundaries parallel to shore were set halfway between active and inactive quadrats along transects (or at the vegetation edge if the first quadrat was active), and colony boundaries perpendicular to shore were set halfway between active and inactive transects. We mapped these boundaries by measuring along transects from plotted GPS points to colony boundary points, with field measurements first corrected for slope (see Regher *et al.* 2006 for details). We connected colony boundary points as directly as possible, but we also used topography to aid in the logical placement of colony boundaries. We calculated a three-dimensional colony surface area 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, Redlands, CA, USA) and the 3D Analyst extension (ESRI).

We included all active quadrats (n = 96) in the estimate of burrow density. The combination of colony area, burrow density, and burrow occupancy generated an estimate of breeding population:

$$\text{Number of burrows} = \text{colony area (ha)} \times \text{burrow density} \left(\frac{\text{burrows}}{\text{ha}} \right) \quad (1)$$

and

$$\text{Number of breeding pairs} = \text{Number of burrows} \times \text{occupancy rate} \quad (2)$$

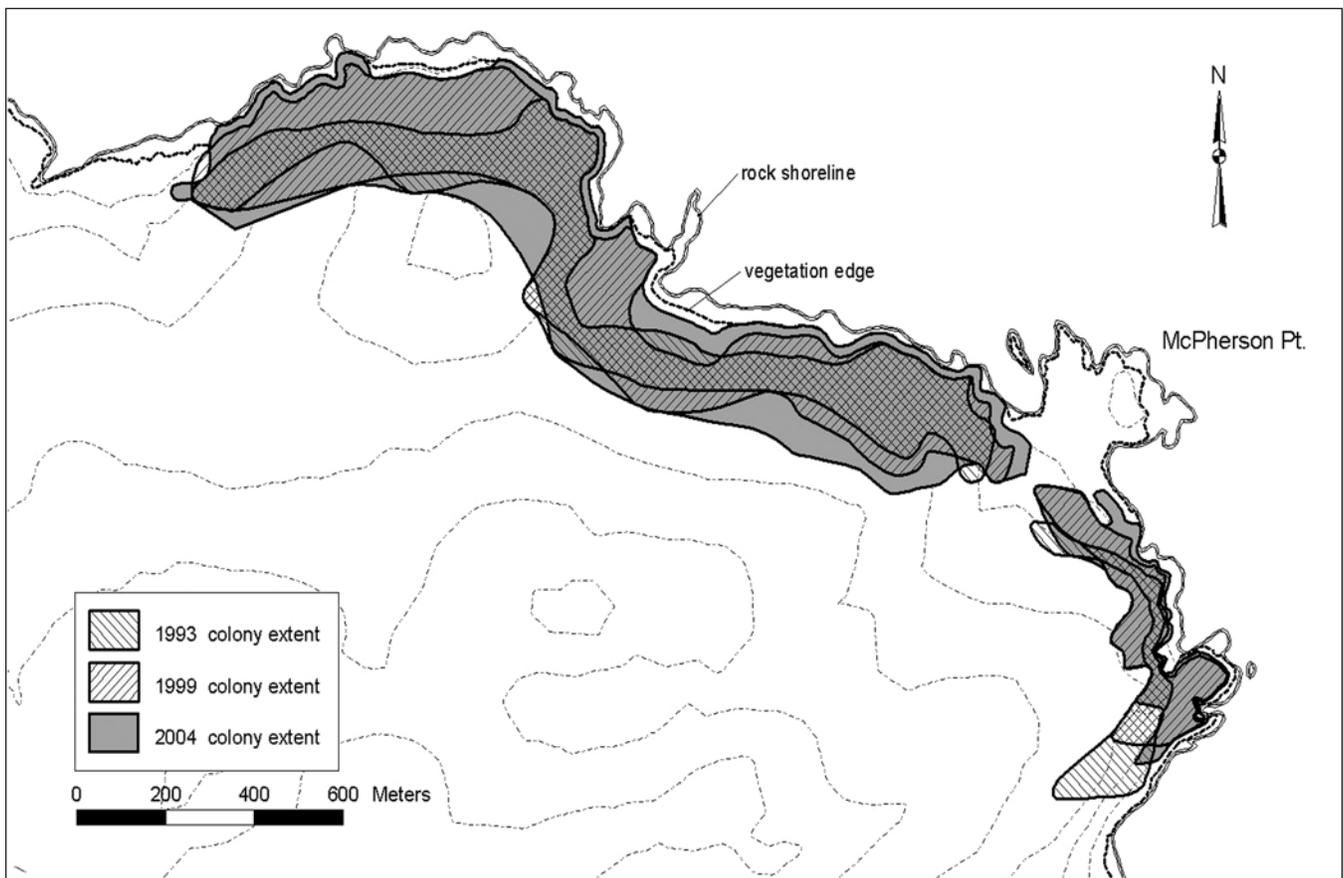


Fig. 2. Comparison of the main Ancient Murrelet *Synthliboramphus antiquus* colony area in the vicinity of McPherson Point on Langara Island in 1993, 1999 and 2004. Fill patterns overlap where colony was present in more than one year.

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

Comparison to previous surveys

We compared our results to surveys conducted before rat eradication in 1981 (Rodway *et al.* 1994), 1988 (Bertram 1989, Rodway *et al.* 1994), and 1993 (Harfenist 1994), and following rat removal in 1999 (Drever 2002). Because of slight differences in methods between years and to improve comparability, we revised results for some surveys. 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). That method derives an area estimate in a fashion analogous to using the digital elevation model, and we did not redo those estimates. For 1993 and 1999, colony area had been estimated simply as average colony length times average width. For those years, we plotted colony boundaries onto transects from 2004 and generated colony surface areas using the digital elevation model. For 1999, we also reinterpreted colony boundaries in five locations from raw data (M. Drever unpubl. data). One methodologic difference could not be resolved: during surveys in 1993 and 1999, the first quadrat in each transect was placed 40 m from shore rather than at the vegetation edge, thereby reducing the potential to detect colony expansion toward the shore. Thus an apparent 20-m wide expansion towards the shore between 1999 and 2004 at some locations could be attributable simply to this difference in methods.

Signs of rat presence

We set 30 rat snap-traps baited with oatmeal and peanut butter 20 m apart within 100 m of the shore in the main part of the colony for three nights (25–28 June). We also looked for signs of rats during surveys and checked for tooth marks in the interior of all depredated eggshells found.

Population trends of other colonies

As an approximate control for changes observed on Langara Island, we summarized data on population trends for other Ancient Murrelet and Cassin's Auklet breeding colonies, with and without invasive rats (or other invasive predators), in the Haida Gwaii archipelago (Fig. 1; see Rodway 1991 for exact locations of islands). Population status at these breeding colonies was assessed in two ways. At some colonies, surveys using transects and quadrats, such as were conducted on Langara Island, provided statistics on colony characteristics. At others, repeat counts of numbers of burrows in permanently marked monitoring plots, established in 1984 and 1985 (Rodway *et al.* 1988), provided a relative index of population status. Monitoring plots were 15×15 m or 20×20 m in size for Ancient Murrelets, and varied in size from 10×10 m to 20×24 m for Cassin's Auklets. We summarized available data for colonies that had been surveyed in more than one year using at least one of the foregoing methods.

RESULTS

Comparison of Langara Island colony characteristics between years

A large, but unquantified reduction in Ancient Murrelet colony area had already occurred on Langara Island by the first survey in 1981 (Rodway *et al.* 1994). Between 1981 and 1993, colony area declined to a quarter of its previous size (Fig. 1). After rat eradication, colony area more than doubled (Figs. 2 and 3). We found no signs of Ancient

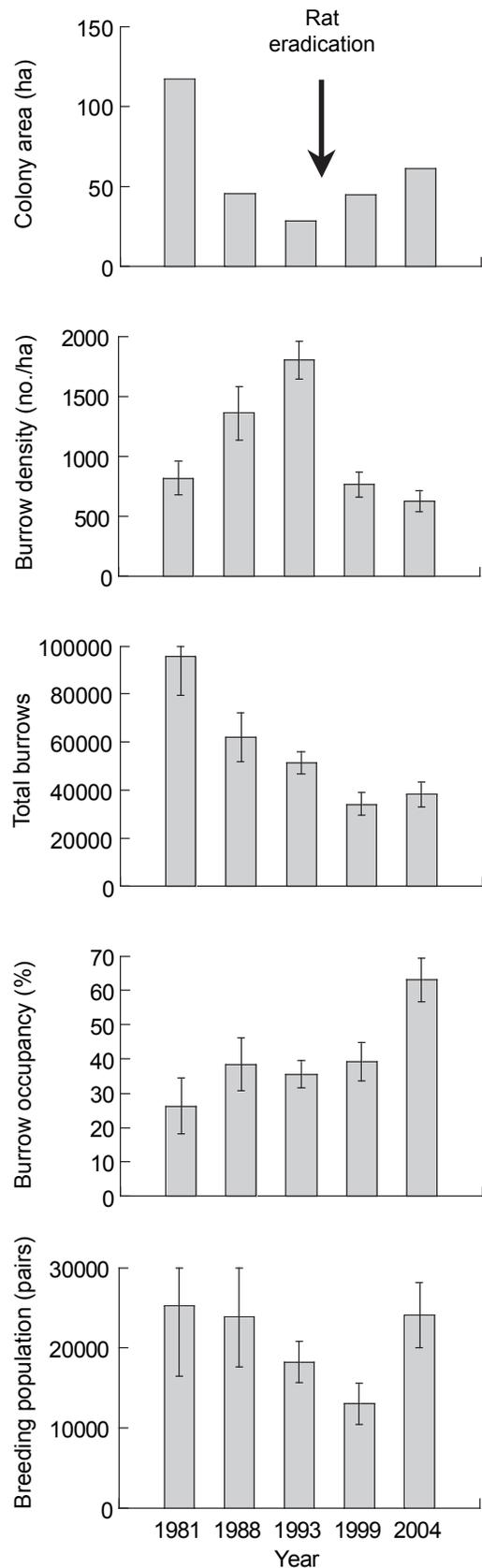


Fig. 3. Changes in component measures used to estimate the breeding population of Ancient Murrelets *Synthliboramphus antiquus* on Langara Island before and after the eradication of Norway Rats *Rattus norvegicus*.

Murrelet activity in the areas searched around Cohoe Point in 2004. Burrow density increased before, then decreased immediately after, rat eradication (Fig. 3). Number of burrows decreased between 1981 and 1999, and has changed little since then (Fig. 3). Occupancy remained low from 1981 to 1999, and increased greatly in 2004. Thus, the breeding population estimated for 2004 was almost twice that estimated for 1999 and was similar to those for 1981 and 1988 (Fig. 3). Hatching success was high in 2004: 91% of occupied burrows showed signs of a successful hatch ($n = 54$ burrows with known content: 31 with fresh egg membranes, 3 with cold eggs, 20 empty).

Other species

In 2004, we discovered a small pocket of Cassin's Auklet burrows close to the vegetation edge, on the north side of the island, within the active Ancient Murrelet colony. We counted 12 burrows within an area approximately 25 m². We could not confirm occupancy directly, but the distinctive signs of Cassin's Auklet (odours, feces, feathers; Rodway *et al.* 1988) indicated that these burrows were active.

Signs of rat presence

We found no signs of rats either in traps or during surveys.

Population trends of other colonies

We summarized data from seven breeding colonies in the Haida Gwaii archipelago, two with, and five without, invasive rats (Tables 1–3). On both islands with rats, Ancient Murrelet breeding populations declined: the population on Lyell Island declined by 22% over a 10-year period, and that on Kunghit Island declined by more than 50% over seven years; the latter colony appeared extirpated by 2004

(Table 1). Estimates of breeding populations of Ancient Murrelets on three colonies free of rats—Frederick, East Copper, and George islands—suggest stable or increasing numbers over 18- and 11-year periods (Table 1). On George Island, numbers of burrows in permanent monitoring plots also increased over 18 years, showing the same trend as the transect surveys (Tables 1 and 2). Numbers of burrows in permanent monitoring plots on Ramsay and Rankine islands suggest that populations in those colonies also were stable or increasing. Estimates of breeding population and burrow counts in permanent monitoring plots suggest that populations of Cassin's Auklets on four islands were relatively stable (Ramsay and East Copper islands) or decreasing (George and Rankine islands; Table 3).

DISCUSSION

Almost a decade after the eradication campaign, Langara Island appears to remain rat-free (see also Kaiser *et al.* 1997, Taylor *et al.* 2000), and seabird recovery is underway. Following rat eradication, the Ancient Murrelet colony expanded, and it had a high occupancy rate and high hatching success in 2004. In addition, Cassin's Auklets, which raise chicks to fledging on the colony and are therefore particularly vulnerable to introduced predators (Moors & Atkinson 1984, Atkinson 1985), had recolonized the island. Thus the rat eradication program is beginning to achieve its goal of restoring Langara Island as an important seabird colony.

Population trends on other nearby colonies support our conclusion that the presence of rats and their removal from Langara Island, and not regional population fluctuations, were responsible for changes

TABLE 1
Component measures used to assess the population status of Ancient Murrelets *Synthliboramphus antiquus* breeding on islands in Haida Gwaii with and without invasive rats (or other invasive predators)^a

| Island | Years surveyed | Colony area (ha) | Burrow density (burrows/ha) | Occupancy (%) | Breeding population [pairs (n)] |
|--------------------------|-------------------|------------------|-----------------------------|---------------|---------------------------------|
| With rats: | | | | | |
| Lyell ^b | 1982 | 126 | 163 | 52 | 10 663 |
| | 1992 | 94.9 | 154 | 57 | 8 332 |
| Kunghit ^c | 1986 | 44 | — | — | 8 800 |
| | 1993 ^d | 11.1 | 600 | 53 | 3 548 |
| Without rats: | | | | | |
| Frederick ^e | 1980 | 109.4 | 1 154 | 54 | 68 407 |
| | 1998 | — | 884 | 73 | 70 321 ^f |
| East Copper ^g | 1985 | 17.8 | 388 | 63 | 4 365 |
| | 2003 | 19.5 | 451 | 69 | 6 056 |
| George ^h | 1985 | 27.1 | 558 | 77 | 11 614 |
| | 1996 | 27.5 | 783 | 81 | 17 384 |

^a Data are presented for colonies that were surveyed in more than one year using line transects with quadrats.

^b Data from Rodway *et al.* (1988) and Lemon (1993).

^c Data from Rodway *et al.* (1988) and Harfenist (1994).

^d A third survey in 2004 suggested that Ancient Murrelets *Synthliboramphus antiquus* have been extirpated from this site (Canadian Wildlife Service unpub. data).

^e Data from Rodway *et al.* (1994), Lemon & Gaston (1999), and Canadian Wildlife Service (unpub. data).

^f Breeding population estimate provisional, pending reanalysis of colony area (Lemon & Gaston 1999).

^g Data from Rodway *et al.* (1988) and Canadian Wildlife Service (unpub. data).

^h Data from Rodway *et al.* (1988) and Lemon (1997).

in Ancient Murrelet colony characteristics and recent recolonization by Cassin's Auklets. Estimates of breeding population and counts of burrows in permanent monitoring plots suggest that other rat-free Ancient Murrelet colonies have been stable or increasing during the last two decades, throughout the period in which the decline on Langara Island was documented (Tables 1 and 2; see also Lemon & Gaston 1999, Hipfner 2004). Further, populations at other colonies with rats have shown declines similar to those at Langara Island. Recolonization by Cassin's Auklets also cannot be linked to regional population trends because recent data suggest that populations in the region are stable or declining (Table 3).

Of the four component measures used to assess the breeding population status of Ancient Murrelets on Langara Island, colony area and burrow density responded rapidly to rat eradication. Colony area declined and mean burrow density increased while rats were on the island, and those trends reversed within four years after rat removal (Fig. 3). Colony area continued to expand through 2004, and mean burrow densities in 1999 and 2004 were much lower than they had been before rat removal. This supports the hypothesis that contraction and concentration of the colony was a direct response to introduced rats, perhaps because anti-predator behaviour, such as predator swamping (Alcock 1984), is more effective at higher densities. However, murrelets showed a limited aggregative response to rat predation, because burrow density did not increase beyond values reported for high-density parts of this colony when first surveyed, or for high-density parts of healthy colonies elsewhere in the region (Rodway *et al.* 1994). Increased mean density can largely be explained by abandonment of low-density habitat. After rat removal, decreases in mean burrow density would logically follow from gradual recolonization of abandoned habitat at low densities. Mean burrow density in 2004 was similar to that seen in 1981 and to those of nearby, rat-free colonies (Rodway *et al.* 1994, Table 1), suggesting that density may have stabilized

and is unlikely to decrease much further as the colony continues to expand. Interestingly, burrow density on Lyell Island (also infested with rats) did not show an increase over a 10-year period, although the colony area decreased to a quarter of its former size (Table 1). Surveys on Lyell Island were not frequent and thorough enough to evaluate the potential cause of this difference.

Number of burrows, burrow occupancy and estimated breeding population did not respond immediately to rat eradication on Langara Island (Fig. 3). Total number of burrows and the estimated breeding population continued to decline in 1999, and occupancy rate remained low. We also detected little change in the number of burrows in 2004 relative to 1999, which suggests that new burrows in the expanding areas of the colony were largely compensating for burrows disappearing from the older, dense parts of the colony. However, burrow occupancy increased markedly in 2004 and was equivalent that year to the median (63%) of other rat-free colonies in British Columbia (Rodway *et al.* 1988). As a result, the estimated breeding population almost doubled between 1999 and 2004.

It may be tempting to postulate that high proportions of unoccupied burrows in the years before 2004 reflected substantial numbers of empty burrows available for use by new recruits, and that the increase in occupancy rate observed on Langara Island in 2004 therefore reflects population growth in spite of a lack of increase in the total number of burrows. However, burrows must be maintained if they are to persist. Recruits tend to dig new burrows rather than to use existing ones (Gaston 1992), and changes in occupancy rate may reflect a number of factors such that interpretation of

TABLE 2
Total number of burrows in permanent monitoring plots, used as indices of population status, for Ancient Murrelets *Synthliboramphus antiquus* on islands in Haida Gwaii without invasive predators^a

| Island | Years surveyed | Plots (n) | Total burrows (n) |
|----------------------|----------------|-----------|-------------------|
| Ramsay ^b | 1984 | 12 | 218 |
| | 2002 | | 345 |
| George ^c | 1985 | 8 | 258 |
| | 1991 | | 323 |
| | 1996 | | 367 |
| Rankine ^d | 2003 | | 374 |
| | 1984 | 8 | 376 |
| | 2000 | | 369 |
| | 2005 | | 385 |

^a Data are presented for colonies that were surveyed in more than one year.

^b Data from Hipfner 2004.

^c Data from Lemon & Gaston (1999), Lemon (1997), and Canadian Wildlife Service (unpub. data).

^d Canadian Wildlife Service (unpub. data).

TABLE 3
Total number of burrows in permanent monitoring plots and breeding population estimates generated from surveys using line transects with quadrats for Cassin's Auklets *Ptychoramphus aleuticus* on islands in Haida Gwaii without invasive predators^a

| Island | Years surveyed | Total burrows (plots) (n) | Breeding population [pairs (n)] |
|--------------------------|----------------|---------------------------|---------------------------------|
| Ramsay ^b | 1984 | 346 (9) | — |
| | 2002 | 380 (9) | — |
| East Copper ^c | 1985 | 237 (6) | 10 876 |
| | 1991 | 239 (6) | — |
| George ^d | 2003 | 199 (6) | 10 611 |
| | 1985 | — | 5 933 |
| Rankine ^e | 1996 | — | 4 326 |
| | 1984 | 397 (8) | — |
| | 2000 | 271 (8) | — |
| | 2005 | 296 (8) | — |

^a Data are presented for colonies that were surveyed using either method in more than one year.

^b Data from Hipfner 2004.

^c Data from Rodway *et al.* (1988) and Canadian Wildlife Service (unpub. data).

^d Data from Rodway *et al.* (1988) and Lemon (1997).

^e Canadian Wildlife Service (unpub. data).

its significance can be complex. Unoccupied burrows are largely maintained by non-breeding birds, including adults that chose not to breed or that desert breeding efforts before laying eggs, and pre-breeding prospecting birds, some of which recruit to the colony (Gaston 1992). Further, changes in burrow density between 1999 and 2004 indicate that burrows can be lost relatively quickly. Thus, low occupancy rates over an extended period of time, such as were observed before rat eradication, suggest that the population contained a relatively large proportion of non-breeding birds that maintained burrows. An increase in occupancy such as was observed in 2004 likely indicates an increase in the ratio of breeding to non-breeding birds, which may reflect changes in population size, but may also be the result of other factors.

The presence of an introduced predator could lead to an elevated proportion of non-breeding birds and unoccupied burrows by affecting population dynamics and behaviour. Persistent low occupancy rates (20%–31%), similar to those at Langara Island before rat eradication, have also been observed over a two-decade period on west Limestone Island in the presence of introduced Raccoons *Procyon lotor* (Rodway *et al.* 1988, Gray 2001), and as compared with colonies without rats, colonies with rats have had lower occupancy rates (Table 1). Predation, perceived predation risk, and predator-induced breeding failure could all lead to reduced occupancy through factors such as decreased local survival of breeders, increased rates of burrow switching within the colony and of emigration to other colonies, decreased breeding propensity (e.g. Hatch & Hatch 1990) and decreased recruitment relative to nearby colonies more attractive to prospecting birds (Thibault 1995). Because many of the pre-breeding birds visiting a colony derive from nearby colonies (Gaston & Jones 1998, Gaston 1992), numbers of prospecting birds that maintain burrows may not be greatly affected by poor local productivity. Thus, after predator removal, adult survival, burrow philopatry, emigration, breeding propensity and recruitment would be expected to normalize and occupancy to increase. Continued low occupancy on Langara Island in 1999 suggests that other environmental conditions delayed recovery, or that there may be a lag before breeding activities normalize. Numbers of burrows continued to decline through 1999, suggesting that mortality and emigration were still greater than recruitment at that time, and that the population was not yet in a recovery phase.

We observed a doubling in the Ancient Murrelet breeding population between 1999 and 2004 (Fig. 3), almost entirely resulting from an increased occupancy rate. If that increase in breeding population reflects population growth, it would represent a very rapid increase for a long-lived species with high adult survivorship and a 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). Substantial movement of individuals among Ancient Murrelet breeding colonies, as documented in banding (Gaston 1992) and genetic (Pearce *et al.* 2002) studies, suggests that rapid population growth through immigration may be feasible. Also, larger clutch size (two eggs), higher recruitment (Gaston 1990) and density-dependent effects from reduced colony size may have enabled this Ancient Murrelet population to increase more rapidly than would be possible for other alcids. However, the fact that the number of burrows did not increase noticeably between 1999 and 2004 suggests that recruitment did not increase markedly, and the larger breeding population was likely attributable to a combination of population growth, effected primarily by increased adult survival and reduced

emigration and by changes in behaviour, such as greater breeding propensity and burrow philopatry.

Successful eradication of rats from an island as large as Langara Island, and clear signs of the island's progress nine years later, is encouraging to island restoration projects globally. Given favourable environmental conditions and protection from other introductions of predators (rats or Raccoons; see also Hartman & Eastman 1999), this historically important seabird colony should continue to recover. Responses of documented Ancient Murrelet colony characteristics to an introduced predator and its removal, and differences in the time-scale of these responses, may aid in the planning and evaluation of similar management action.

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REFERENCES

- ALCOCK, J. 1984. Animal behavior: an evolutionary approach. 3rd ed. Sunderland: Sinauer Associates. 596 pp.
- ATKINSON, I.A.E. 1985. The spread of commensal species of *Rattus* to oceanic islands and their effects on island avifaunas. In: Moors, P.J. (Ed). Conservation of island birds: case studies for the management of threatened island species. Technical Publication No. 3. Cambridge, UK: International Council for Bird Preservation. pp. 35–81.
- BERTRAM, D.F. 1989. The status of Ancient Murrelets breeding on Langara Island, British Columbia, in 1988. Technical Report Series No. 59. Delta, BC: Canadian Wildlife Service. 67 pp.
- 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. & NAGORSEN, D.W. 1995. Introduced rats, *Rattus* spp., on the Queen Charlotte Islands: implications for seabird conservation. *Canadian Field-Naturalist* 109: 6–10.
- BOERSMA, P.D., CLARK, J.A. & HILLGARTH, N. 2002. Seabird conservation. In: Schreiber, E.A. & Burger, J. (Eds). Biology of marine birds. London: CRC Press. pp. 559–579.
- BURGER, J. & GOCHFELD, M. 1994. Predation and effects of humans on island-nesting seabirds. In: Nettleship, D.N., Burger, J. & Gochfeld, M. (Eds). Seabirds on islands: threats, case studies and action plans. Cambridge, UK: BirdLife International. pp. 39–67.
- 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. Delta, BC: Canadian Wildlife Service. 35 pp.

- 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. London: Poyser. 249 pp.
- GASTON, A.J. & JONES, I.L. 1998. The auks: Alcidae. Oxford: Oxford University Press. 349 pp.
- GRAY, J. 2001. East Limestone Island camp: report on the 2000 field season. In: Gaston, A.J. (Ed). Laskeek Bay Research 10. Queen Charlotte City, BC: Laskeek Bay Conservation Society. pp. 9–15.
- HARFENIST, A. 1994. Effects of introduced rats on nesting seabirds of Haida Gwaii. Technical Report Series No. 218. Delta, BC: Canadian Wildlife Service. 52 pp.
- HARRIS, M.P. 1983. Biology and survival of the immature puffin *Fratercula arctica*. *Ibis* 125: 56–73.
- HARRIS, M.P. 1984. The puffin. Calton, UK: T & AD Poyser. 224 pp.
- HARTMAN, L.H. & EASTMAN, D.S. 1999. Distribution of introduced Raccoons *Procyon lotor* on the Queen Charlotte Islands: implications for borrow-nesting seabirds. *Biological Conservation* 88: 1–13.
- HATCH, S.A. & HATCH, M.A. 1990. Components of breeding productivity in a marine bird community: key factors and concordance. *Canadian Journal of Zoology* 68: 1680–1690.
- HIPFNER, J.M. 2004. Surveys of permanent seabird monitoring plots on Ramsay Island, Gwaii Haanas, in June 2002. In: Gaston, A.J. (Ed). Laskeek Bay Research 13. Queen Charlotte City, BC: Laskeek Bay Conservation Society. pp 35–39.
- HUDSON, P.J. 1985. Population parameters for the Atlantic Alcidae. In: Nettleship, D.N. & Birkhead, T.R. (Eds). The Atlantic Alcidae. London, UK: Academic Press. pp. 233–261.
- JOUVENTIN, P., BRIED, J. & MICOL, T. 2003. Insular bird populations can be saved from rats: a long-term experimental study of White-chinned Petrels *Procellaria aequinoctialis* on Ile de la Possession (Crozet Archipelago). *Polar Biology* 26: 371–378.
- KAISER, G.W., TAYLOR, R.H., BUCK, P.D., ELLIOTT, J.E., HOWALD, G.R. & DREVER, M.C. 1997. The Langara Island Seabird Habitat Recovery Project: eradication of Norway Rats – 1993–1997. Technical Report Series No. 304. Delta, BC: Canadian Wildlife Service. 49 pp.
- LEMON, M.J.F. 1993. Survey of Ancient Murrelet colony at Dodge Point on Lyell Island in 1992. In: Gaston, A.J. & Lawrence, A. (Eds). Laskeek Bay Research 3. Queen Charlotte City, BC: Laskeek Bay Conservation Society. pp. 38–51.
- LEMON, M.J.F. 1997. Seabird colony monitoring on George Island, 1996. In: Gaston, A.J. (Ed). Laskeek Bay Research 7. Queen Charlotte City, BC: Laskeek Bay Conservation Society. pp 27–48.
- LEMON, M.J.F. & GASTON, A.J. 1999. Trends in Ancient Murrelet populations since 1980. Bird Trends No. 7. Delta, BC: Canadian Wildlife Service. pp. 22–25.
- MOORS, P.J. & ATKINSON, I.A.E. 1984. Predation on seabirds by introduced animals, and factors affecting its severity. In: Croxall, J.P., Evans, P.G.H. & Schreiber, R.W. (Eds). Status and conservation of the world's seabirds. Technical Publication No. 2. Cambridge, UK: International Council for Bird Preservation. pp. 667–690.
- PEARCE, R.L., WOOD, J.J., ARTUKHIN, Y., BIRT, T.P., DAMUS, M. & FRIESEN, V.L. 2002. Mitochondrial DNA suggests high gene flow in Ancient Murrelets. *Condor* 104: 84–91.
- REGEHR, H.M., RODWAY, M.S., LEMON, M.J.F. & HIPFNER, J.M. 2006. Status of the Ancient Murrelet colony on Langara Island in 2004, nine years after eradication of introduced rats. Technical Report Series No. 445. Delta, BC: Canadian Wildlife Service. 39 pp.
- RODWAY, M.S. 1991. Status and conservation of breeding seabirds in British Columbia. In: Croxall, J.P. (Ed). Seabird status and conservation: a supplement. Technical Publication No. 11. Cambridge, UK: International Council for Bird Preservation. pp. 43–102.
- RODWAY, M.S., LEMON, M.J.F. & KAISER, G.W. 1988. British Columbia seabird colony inventory: Report #1 – East coast Moresby Island. Technical Report Series No. 50. Delta, BC: Canadian Wildlife Service. 276 pp.
- RODWAY, M.S., LEMON, M.J.F. & KAISER, G.W. 1994. British Columbia seabird colony inventory: Report #6 – Major colonies on the west coast of Graham Island. Technical Report Series No. 95. Delta, BC: Canadian Wildlife Service. 108 pp.
- TAYLOR, R.H., KAISER, G.W. & DREVER, M.C. 2000. Eradication of Norway Rats for recovery of seabird habitat on Langara Island, British Columbia. *Restoration Ecology* 8: 151–160.
- THIBAUT, 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. & BROOME, K.G. 2003. From small Maria to massive Campbell: forty years of rat eradications from New Zealand islands. *New Zealand Journal of Zoology* 30: 377–398.