USE OF PERMANENT PLOTS TO MONITOR TRENDS IN BURROW-NESTING SEABIRD POPULATIONS IN BRITISH COLUMBIA

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SUMMARY

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We describe the use of permanent plots for monitoring population trends of burrow-nesting seabirds in British Columbia and test the assumption that trends in plot counts mirror trends in overall population size. A total of 97 plots for Ancient Murrelets *Synthliboramphus antiquus*, Cassin's Auklets *Ptychoramphus aleuticus*, Rhinoceros Auklets *Cerorhinca monocerata*, and Tufted Puffins *Fratercula cirrhata* were established in the 1980s. Plots were subjectively distributed in higher-density nesting areas of major colonies. Since then, numbers of Ancient Murrelet, Rhinoceros Auklet, and Tufted Puffin burrows increased or remained stable at monitored colonies, except on Pine Island, where burrows decreased for Rhinoceros Auklets. Declines were apparent for Cassin's Auklets, especially on Triangle Island, where numbers of burrows in plots declined 2.5% per year, resulting in a 40% decline in 20 years—a potential loss in that region of more than 20% of the estimated world breeding population. A serious threat to a majority of the world's Ancient Murrelet population from introduced predators was undetected by the permanent plot scheme because colonies with predators were not sampled. This highlights the need for a broad sampling of colonies and the importance of additional surveillance and study of breeding populations. Close agreement was found in the trend information provided by permanent monitoring plots and full-colony transect surveys. Both methods revealed significant differences when burrow numbers changed 3–4% annually. Results suggest that six to eight subjectively placed permanent plots reveal accurate trends in burrow numbers within a colony.

Key words: burrowing alcids, burrow counts, permanent plots, British Columbia, population declines, introduced predators

INTRODUCTION

Estimating breeding populations at colony, regional and global scales, and detecting trends in those populations over time, are prerequisites to informed management and conservation of seabird species. Accurate population estimates are often laborious and expensive to obtain. This is especially so for burrow-nesting species, which are inconspicuous and often nocturnal on their breeding grounds and for which populations cannot be counted directly but must be estimated from derived parameters (Nettleship 1976, Evans 1980). Repeated counts of nests or birds within permanently established monitoring plots have been used as an expedient alternative to full-scale population surveys to provide indicators of population trends (Walsh *et al.* 1995, Anker-Nilssen *et al.* 1996, Byrd & Dragoo 1997, Barrett 2001). Such counts rarely provide estimates of population size because plots are usually distributed subjectively and are not representative of entire colonies, but trends in the counts are thought to reflect trends in population size. Here we describe the use of permanent monitoring plots in British Columbia (BC), test the assumption that trends in plot counts mirror trends in overall population size, and discuss some of the problems we have encountered in repeating and interpreting counts.

METHODS

Design of the permanent plot system

Intensive surveys to obtain baseline population data for most colonies of burrow-nesting seabirds in BC were conducted in the 1980s by the Canadian Wildlife Service (Rodway & Lemon 1990, 1991a,b, Rodway *et al.* 1988, 1990a,b, 1994). Surveys involved mapping colony areas, measuring burrow density using a systematic sampling scheme of quadrats along transects, and determining burrow occupancy rates by excavating samples of burrows, thus yielding the three parameters required to estimate breeding populations. Designs for a monitoring program were developed, and permanent plots were established, during the surveys. Targeted species included Ancient Murrelets *Synthliboramphus antiquus*, Cassin's Auklets *Ptychoramphus aleuticus*, Rhinoceros Auklets *Cerorhinca monocerata*, and Tufted Puffins *Fratercula cirrhata*, for which BC colonies house a majority or, in the case of Tufted Puffins, a small but concentrated proportion of, estimated world populations (Rodway 1991). The objectives of the program were to provide representation from colonies that in total supported 80% of provincial populations and included the different oceanographic regions of the coast where the species nested (Fig. 1). Plots were sized and subjectively distributed in high-density nesting areas to ensure that they contained adequate numbers of burrows to allow modest changes to be detected. The number of burrows contained within permanent plots generally constituted 1–3% of the estimated number of burrows in a colony. Ninety-seven plots were established (Table 1), ranging in size from 10 × 10 m to 20 × 20 m and representing four of the six regions identified in the original design. Plots intended for the main colonies of Ancient Murrelet and Cassin's Auklet on the west coast of Haida Gwaii and of Cassin's Auklet and Rhinoceros Auklet off the central mainland coast have yet to be established (Fig. 1).

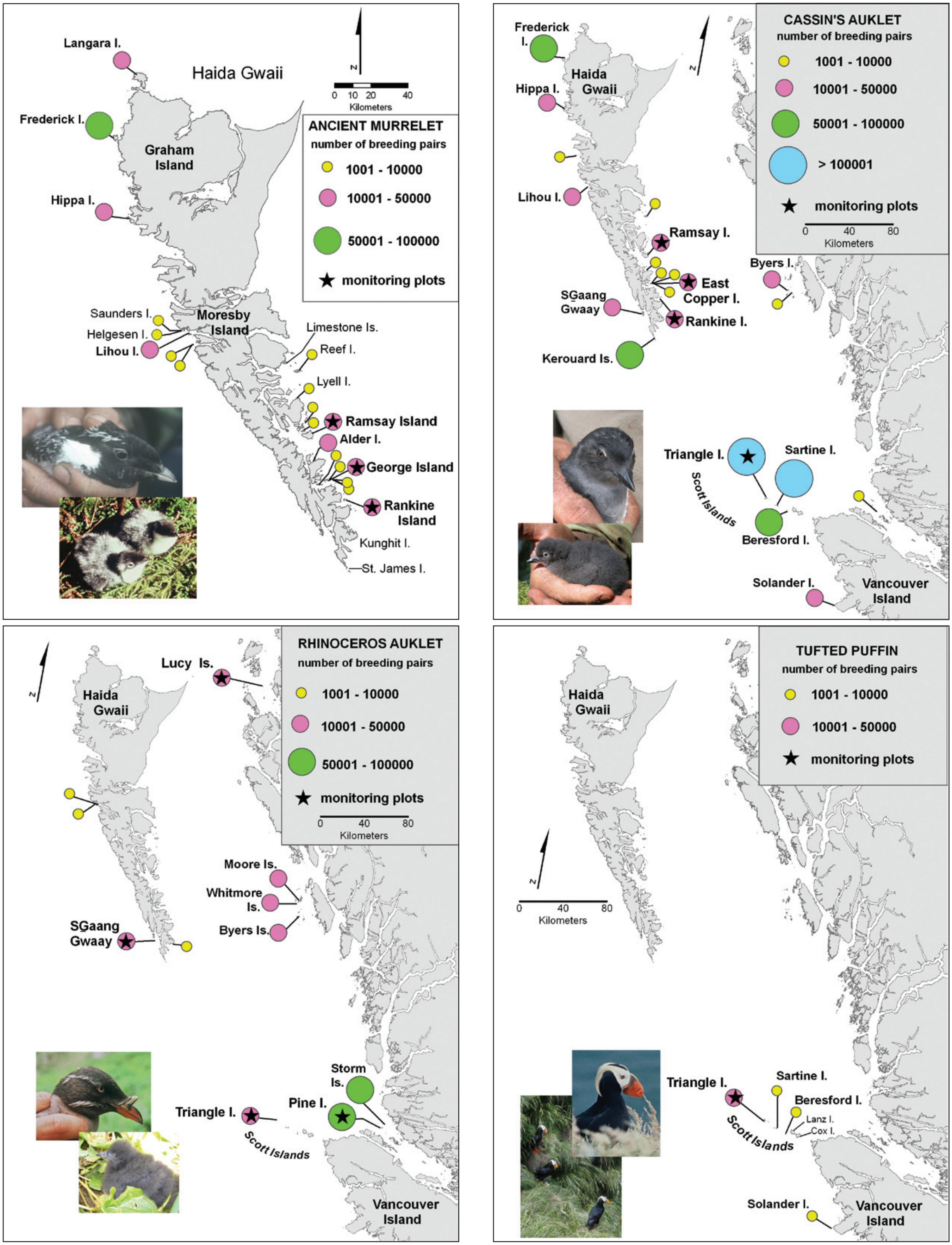

Fig. 1. Major colonies of Ancient Murrelet, Cassin's Auklet, Rhinoceros Auklet, and Tufted Puffin in British Columbia and locations where permanent monitoring plots have been established.

TABLE 1
Permanent plots established for monitoring population trends of burrow-nesting seabirds in British Columbia

Species	Island	No. of plots	Plot size	Year established
Ancient Murrelet	Ramsay	12	20 m × 20 m	1984
	George	8	20 m × 20 m	1985
	Rankine	8	15 m × 15 m	1984
Cassin's Auklet	Ramsay	9	15 m × 15 m	1984
	East Copper	6	10 m × 10 m	1985
	Rankine	8	10 m × 10 m	1984
	Triangle	15	10 m × 10 m	1989
Rhinoceros Auklet	SGaang Gwaay	8	10 m × 10 m	1985
	Lucy	5	10 m × 10 m	1984
	Pine	8	10 m × 10 m	1984
	Triangle	6	10 m × 10 m	1984
Tufted Puffin	Triangle	4	10 m × 10 m	1984

The intention was to resurvey plots at five-year intervals. This goal has been achieved at some colonies, providing time series of up to 25 years (Lemon 1992, 1993, 1997, 2003, 2005, Lemon & Gaston 2000, Hipfner 2004). Additional plots were to be added to the scheme if colony areas expanded or if plots were lost due to landscape changes such as slides or massive blowdowns. Only two of the 97 plots have been lost to such events: a large windfall obliterated one Rhinoceros Auklet plot on SGaang Gwaay sometime before 2006, and one Rhinoceros Auklet plot on Triangle Island was eliminated by a landslide sometime between 1989 and 1994. We re-established the plot on Triangle Island in 2009 after the area had revegetated and Rhinoceros Auklets were once again nesting. Two additional Rhinoceros Auklet plots were established on Triangle Island in 2009 in areas of colony expansion.

Marking plots and counting burrows

We staked and colour-coded plot corners with aluminum tubing 1.0–1.5 m in length, and secured an engraved aluminum identification tag to one corner or to a nearby tree. Plot locations were carefully mapped in relation to surrounding topographic features and subsequently georeferenced.

Consistent criteria were used to enumerate burrows. A tunnel entrance was counted as a burrow if the tunnel extended beyond an arm inserted to the elbow, or if there was an obvious nest cup. Shorter burrows without nest cups were identified as "starts" and

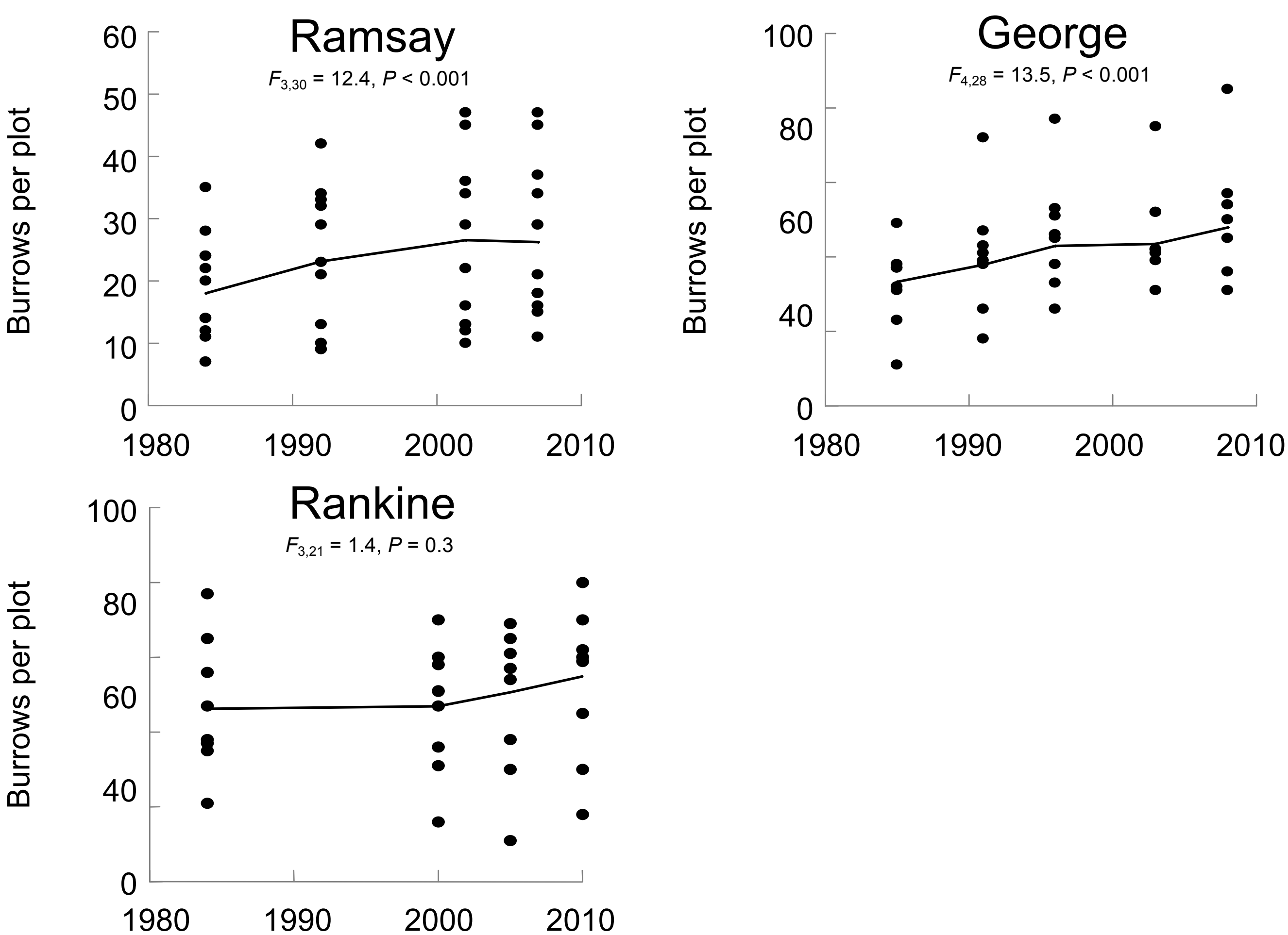

Fig. 2. Changes in numbers of Ancient Murrelet burrows in permanent monitoring plots on the east coast of Haida Gwaii.

tallied separately. Entrances that interconnected within elbow length were recorded as one burrow with multiple entrances. Disturbance was kept to a minimum, and burrows were not excavated to determine contents.

Statistics

Repeated-measures analyses in a general linear model were used to assess trends in burrow numbers for each colony, and trend lines were fitted to the data using a locally weighted scatterplot smoothing (LOWESS) function (tension = 0.5). Only plots with complete time series were used in analyses. Statistical significance was set at $P < 0.05$ for all tests.

RESULTS

Trends in permanent plot counts

Data from repeated surveys of permanent plots have indicated several trends. Numbers of Ancient Murrelet burrows have increased (Ramsay and George islands) or remained stable (Rankine Island) at monitored colonies on the east coast of Haida Gwaii (Fig. 2).

Trends for Cassin's Auklets were mostly negative, especially at the centre of their breeding population in the Scott Islands (Fig. 1). In Haida Gwaii, a decline of 32% was detected on Rankine Island between 1984 and 2000, with perhaps some recovery between 2000 and 2010, while the colony on Ramsay Island appeared relatively stable (Fig. 3). Numbers of burrows in plots declined 16% between 1991 and 2003 on East Copper Island, but differences were not significant. On Triangle Island, there has been a steady decline (2.5% per year) in numbers of burrows counted in permanent plots between 1989 and 2009, resulting in a 40% decline in 20 years (Fig. 3). Numbers of Cassin's Auklet burrows in Rhinoceros Auklet permanent plots on Triangle Island, which were established earlier (1984), increased from 1984 to 1989, then decreased steadily to 2009 (Fig. 4), suggesting that the decline in the Cassin's Auklet breeding population began around 1990. Data from transect surveys of the Rhinoceros Auklet colony on the island in 1984 and 1989 showed the same increasing trend in Cassin's Auklets during that period (0.24 and 0.65 burrows/m^2 in 1984 and 1989, respectively; $F = 8.3$, $P = 0.004$).

Counts of Rhinoceros Auklet burrows in permanent plots on Triangle Island from 1984 to 2009 suggest an increasing trend (Fig. 5). Numbers of burrows were higher in 2009 than in all previous survey years (post hoc tests for repeated measures: all $P < 0.05$, except $P = 0.1$ in 1989). Colony boundaries have also expanded, and numbers of Rhinoceros Auklet burrows identified in Cassin's Auklet plots increased from eight in one plot in 1989 to 71 in four plots in 2009. Positive change was also observed at monitored colonies in Haida Gwaii and on the

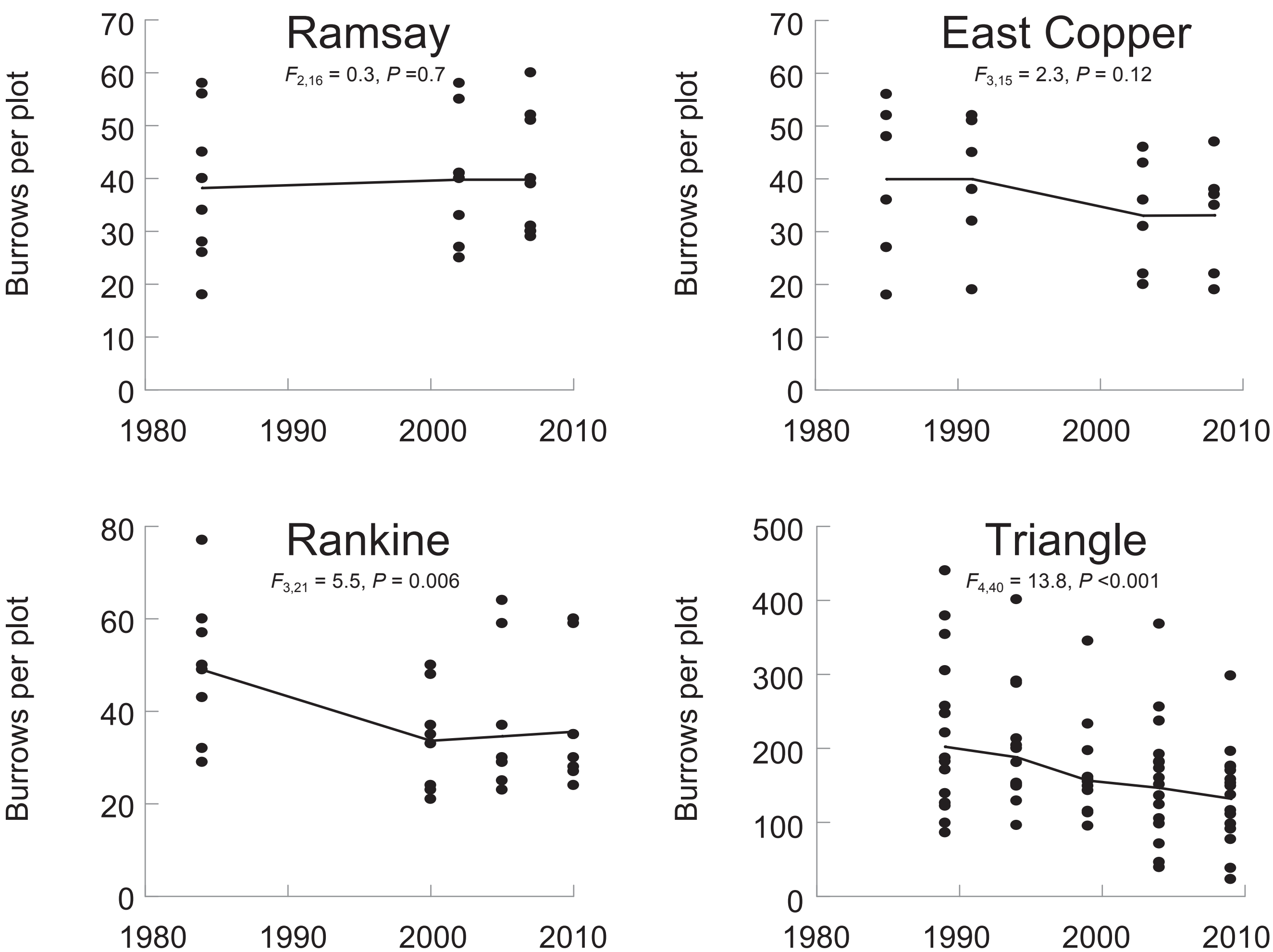

Fig. 3. Changes in numbers of Cassin's Auklet burrows in permanent monitoring plots on the east coast of Haida Gwaii (Ramsay, East Copper and Rankine islands) and in the Scott Islands (Triangle Island).

northern mainland coast (Fig. 5). Burrow numbers were higher in 2011 than in 2006 and 1985 on SGaang Gwaay (post hoc tests: both $P < 0.05$). Numbers of burrows increased 34% between 1984 and 1987 on Lucy Island, although changes were not significant (post hoc test: $P = 0.05$). In contrast, numbers of Rhinoceros Auklet burrows in permanent plots declined 21% between 1984 and 2001 on Pine Island (Fig. 5). Numbers there have been stable since 2001 (pairwise comparisons showing lower numbers in 2001, 2006 and 2011 than in 1984, 1987 and 1990; all $P < 0.05$).

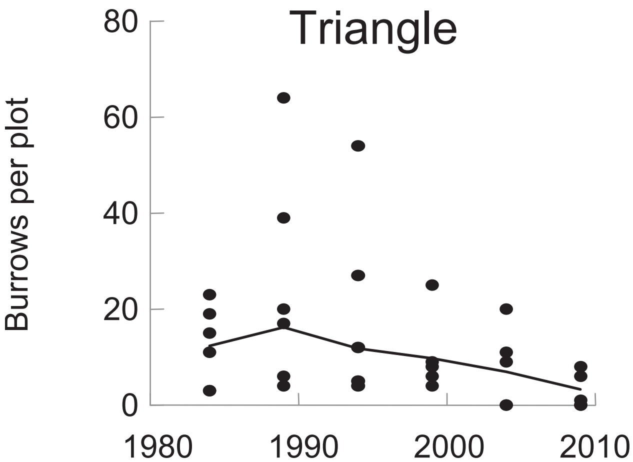

Fig. 4. Changes in numbers of Cassin's Auklet burrows in Rhinoceros Auklet permanent monitoring plots on Triangle Island.

Interannual changes in numbers of burrows in Tufted Puffin plots have shown a pattern similar to Rhinoceros Auklets on Triangle Island, except there is no indication of an overall increasing trend (Fig. 6). For both puffin species, burrow numbers were lowest in 1994 (<1989 and <1999 for Rhinoceros Auklets and <1989 for puffins; all post hoc tests $P < 0.05$) and 2004 (<1999 for Rhinoceros Auklets and <1989 and <1999 for puffins; all $P < 0.05$).

Comparing permanent plots and transect surveys

In four cases, counts of burrows in permanent monitoring plots and full-colony transect surveys were replicated concurrently (Fig. 7). Close agreement was found in the trend information provided by these two methods; estimates of annual change were within 0.1 to 1.4 percentage points of each other (Table 2).

Burrow density estimates were higher in permanent plots than in transect plots (Fig. 7). However, estimates of the burrow density for Cassin's Auklet on East Copper Island from the two methods converged between 1985, when permanent plots were established, and 2003 (Fig. 7).

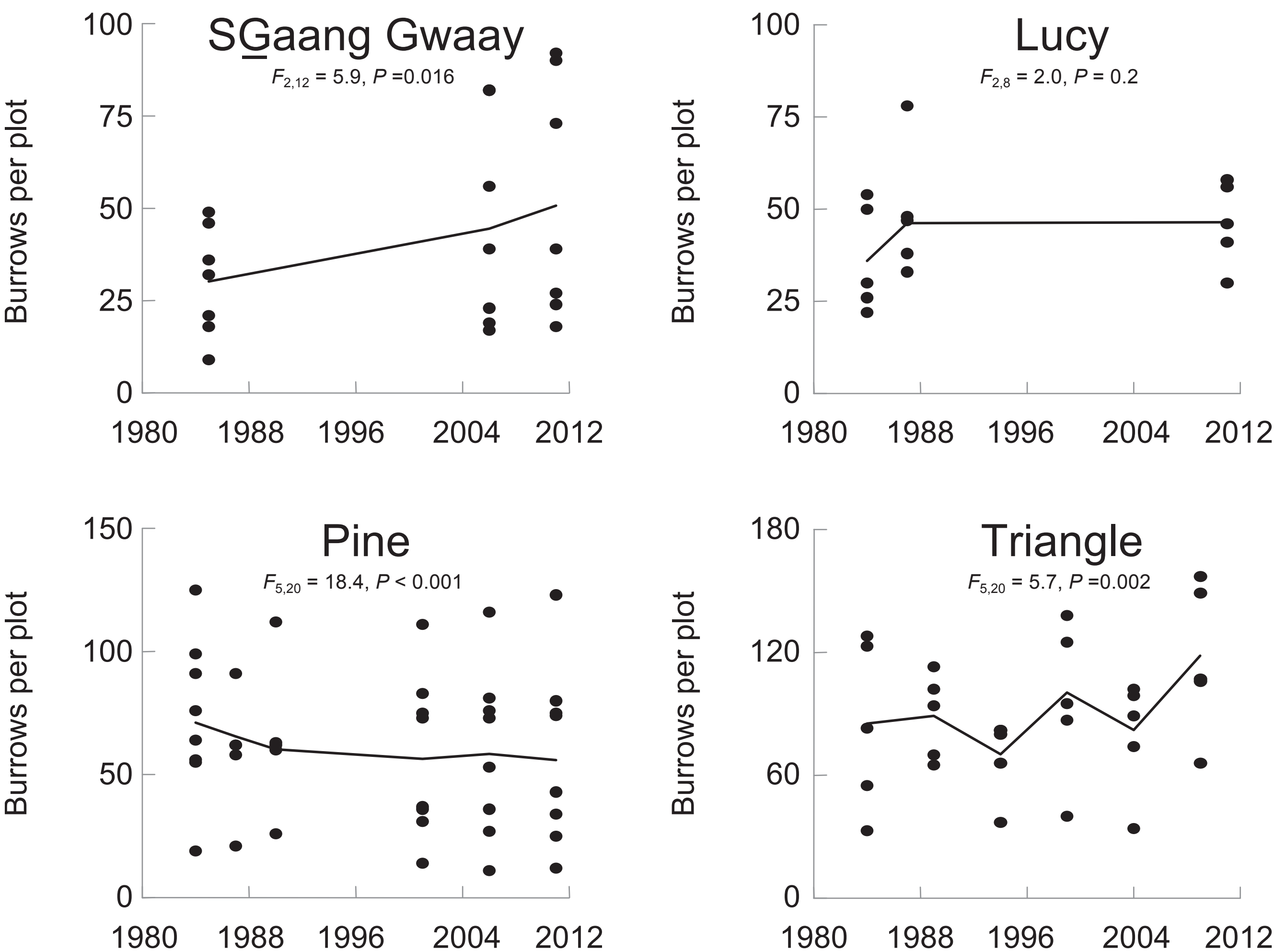

Fig. 5. Changes in numbers of Rhinoceros Auklet burrows in permanent monitoring plots in Haida Gwaii (SGaang Gwaay), the northern mainland coast (Lucy Islands), Queen Charlotte Strait (Pine Island), and in the Scott Islands (Triangle Island).

DISCUSSION

Trends in permanent plot counts

Repeated surveys of permanent plots have indicated increasing or stable trends in the numbers of Ancient Murrelet burrows at monitored colonies on the east coast of Haida Gwaii (Lemon 1992, 1993, 1997, 2003, 2005, Lemon & Gaston 1998, Hipfner 2004). Populations have also increased on Reef Island in the same area (Gaston & Lemon 1996, Gaston *et al.* 2009). This is in sharp contrast to trends at colonies affected by introduced mammalian predators (Summers & Rodway 1988, Gaston 1994). Expanding populations of introduced rats (*Rattus rattus* and *R. norvegicus*) and Raccoons (*Procyon lotor*) threaten Ancient Murrelet and other breeding seabird populations throughout the Haida Gwaii archipelago (Rodway 1991, Bertram & Nagorsen 1995, Gaston & Masselink 1997, Harfenist & Kaiser 1997, Hartman & Eastman 1999).

Rats have been recorded from 18 islands in the archipelago and have been implicated in the extirpation or decline of burrow-nesting species from colonies on Langara and the adjacent Cox and Lucy islands at the northwest tip of Haida Gwaii, St. James and Kunghit islands at the southern tip of the archipelago, and on Lyell, Murchison and Bischof islands along the east coast of Moresby Island (Fig. 1; Rodway 1991, Bertram & Nagorsen 1995). We note, however, that the extirpation of Ancient Murrelets from Lucy Island may have resulted from the introduction to that island in the 1920s of Marten *Martes americana nesophila,* which are indigenous to the larger islands of Haida Gwaii (Cumming 1931). Raccoons have spread the length of the archipelago since their introduction in the 1940s, and are likely responsible for

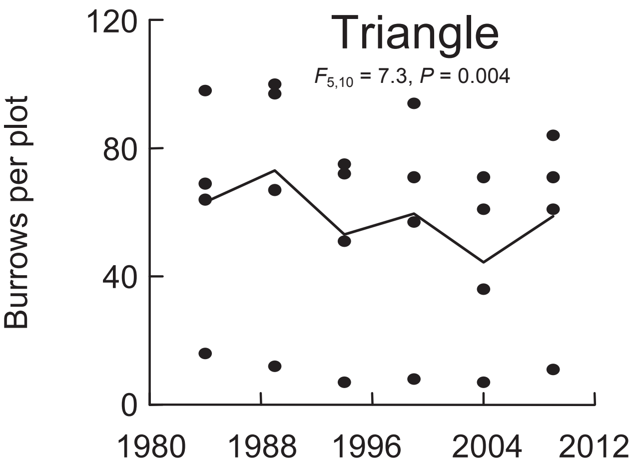

Fig. 6. Changes in numbers of Tufted Puffin burrows in permanent monitoring plots on Triangle Island.

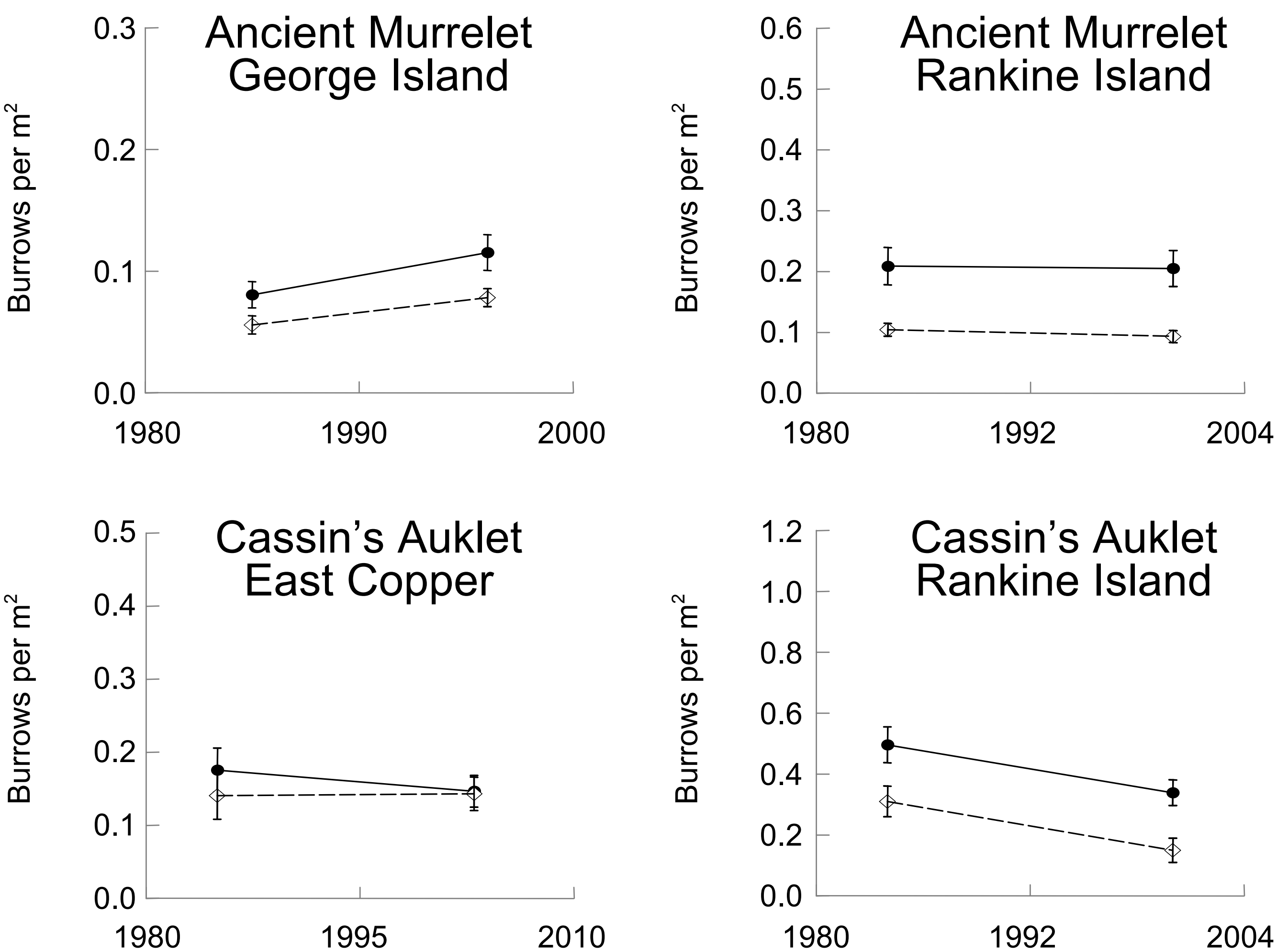

Fig. 7. Comparison of trends in burrow density revealed by concurrent surveys of permanent monitoring plots (circles) and colony-wide transects (diamonds).

the elimination or reduction of colonies on Limestone, Sels, Boulder and Sea Pigeon islands along the east coast of Moresby Island, and on Saunders, Helgesen and Instructor islands in Englefield Bay on the west coast of Moresby Island (Summers & Rodway 1988, Gaston & Masselink 1997, Hartman & Eastman 1999). Eradication programs for rats have been successful on Langara, Cox and Lucy islands (Kaiser *et al.* 1997, Taylor *et al.* 2000) and St. James Island (Golumbia 2000), and are underway on Bischof and nearby islands. Follow-up investigations instill optimism for the recovery on Langara Island of what once may have been the largest colony of Ancient Murrelets anywhere (Regehr *et al.* 2007). Control programs for Raccoons have reduced predation on Ancient Murrelets on East Limestone Island (Hartman *et al.* 1997) and may have eliminated those predators from Helgesen Island (Harfenist *et al.* 2000), although there was no sign of recovery by burrowing seabirds on Helgesen Island in 2004 (M. Hipner & A.J. Gaston, unpubl. data). Raccoons have demonstrated their capacity to reach most major seabird colonies in Haida Gwaii, and continued vigilance will be required to detect and remove invading individuals before nesting populations are decimated. This will be a perennial problem for resource managers until an archipelago-wide solution becomes practical. Other than Langara Island, impacted colonies have been relatively small and were not included in the permanent monitoring plot scheme. Thus, changes at those colonies have gone undetected by the scheme. Elsewhere in the province, introductions in the 1930s of Mink *Neovison vison* and Raccoon eliminated nesting seabirds on Lanz and Cox islands in the Scott Island chain (Fig. 1; Carl *et al.* 1951). Removal of those predators has been proposed (Hipfner *et al.* 2010).

Declining trends for Cassin's Auklets were apparent at the centre of their breeding population in the Scott Islands, where numbers of burrows in permanent plots declined at a rate of 2.5% per year, resulting in a 40% decline between 1989 and 2009. Trends in the numbers of Cassin's Auklet burrows in Rhinoceros Auklet plots suggested that the decline in the Cassin's Auklet breeding population began around 1990. A declining trend since 1990 agrees with other indicators from productivity and survival studies and has likely been mediated by changing oceanographic conditions (Bertram *et al.* 2001, Hedd *et al.* 2002, Bertram *et al.* 2005). If trends in permanent plots on Triangle Island are representative of Cassin's Auklet population trends throughout the Scott Islands, as a recent comparative survey of neighbouring Sartine Island suggests (Hipfner *et al.* 2010), then the loss could be ~800 000 birds, constituting more than 20% of the estimated world breeding population of Cassin's Auklet (Rodway 1991).

On the east coast of Haida Gwaii, numbers of Cassin's Auklet burrows declined significantly only on Rankine Island between 1984 and 2000, while other monitored colonies on Ramsay and East Copper islands appeared relatively stable (Lemon 2003, 2005; Hipfner 2004). Inconsistent trends among colonies suggest that declines are not widespread in that region. The decline on Rankine Island may be related more to habitat changes than to demographic factors, although similar trends in burrow density from comparative transect surveys (Fig. 7) indicated that changes were island-wide and thus likely represent a real population decrease on Rankine Island during that period. Substantial changes in vegetation cover and loss of burrowing habitat, primarily resulting from windfalls and dense regeneration of Sitka Spruce *Picea sitchensis* seedlings, occurred across the island and in seven of the eight Cassin's Auklet permanent plots between 1984 and 2005 (Lemon 2005). Non-significant changes on East Copper Island may also have been related to habitat alteration within the permanent plots (Lemon 2003; see below). Differing trends in the Scott Islands and Haida Gwaii are consistent with results of comparative studies that indicate relatively robust Cassin's Auklet populations, with higher adult survival and chick production on Frederick Island on the west coast of Haida Gwaii than on Triangle Island (Bertram *et al.* 2005, 2009). Establishment of monitoring plots at designated colonies along the west coast (Fig. 1) would help confirm whether trends on the east and west coasts of Haida Gwaii are similar.

Rhinoceros Auklets established new colonies in BC through the latter part of the 20th century (Campbell *et al.* 1990). The colony on Triangle Island was first reported in 1966 (Hancock 1970), although it may have been present earlier (Carl *et al.* 1951). Data from permanent plots suggest the population is still increasing and colony boundaries are still expanding. Increases were also observed at monitored colonies in Haida Gwaii and on the northern mainland coast. In contrast, numbers of Rhinoceros Auklet burrows in permanent plots declined 21% over a 17-year period on Pine Island. Reasons for the discrepant, negative trend in Queen Charlotte Strait are unclear, although nestling growth was poor on Pine Island in the 1980s (Bertram *et al.* 1991).

Numbers of Tufted Puffin burrows in permanent plots on Triangle Island revealed no overall trend. Interestingly, variation in numbers of Tufted Puffin burrows showed a pattern similar to that for Rhinoceros Auklet burrows on that island. Numbers of burrows of both puffin species showed a local peak in 1999, a season of particularly good reproductive performance following a series of poorer seasons in the 1990s (Gjerdrum *et al.* 2003, Hedd *et al.* 2006). Concordance between annual productivity and burrow numbers was unexpected. Because burrows may persist over several seasons, we thought that changes in burrow numbers would lag behind changes in productivity or population. This is more likely

TABLE 2
Comparison of trends in estimates of burrow density from permanent monitoring plots and colony-wide transect surveys

			Permanent plots			Transect surveys		
Species	**Island**	**Years**	**Annual trend (%)[a]**	*t*	*P*	**Annual trend (%)[a]**	*F*	*P*
Ancient Murrelet	George	1985–1996	+4.4	4.85	0.002	+3.1	4.49	0.036
	Rankine	1984–2000	–0.2	0.34	0.746	–0.7	0.57	0.453
Cassin's Auklet	East Copper	1985–2003	–1.3	1.80	0.132	+0.1	0.01	0.946
	Rankine	1984–2000	–4.3	3.32	0.013	–4.4	5.65	0.021

[a] Percent annual change is based on mean burrow density from the earlier transect survey (1984 or 1985).

the case where burrows are located in relatively stable soil, as is generally the case in forested habitats where tree roots provide structural support. On Triangle Island, slopes are steep and soil is easily eroded in many areas by the traffic of nesting birds. Because burrows in permanent plots have been counted late in the nesting season, unused or failed burrows may have been eroded or filled in by the time plots are surveyed, so that the number of burrows counted reflects current-year productivity.

Comparing permanent plots and transect surveys

Close agreement was found in the trend information provided by permanent monitoring plots and full-colony transect surveys, giving us greater confidence that burrow counts from permanent plots indicate valid trends in burrow density within a colony. Both methods revealed significant differences when burrow numbers changed 3–4% annually. One advantage of permanent plots is that more powerful statistical analyses incorporating repeated measures can be used to detect trends. Comparing trends detected by these two methods suggests that as few as six to eight subjectively placed permanent plots reveal accurate trends in overall burrow density within a colony. Smaller numbers of plots failed to detect substantial changes — on Lucy Islands, for example — and additional plots are needed to increase sensitivity in those cases. Anker-Nilssen *et al.* (1996) also concluded that repeat counts from six to 10 monitoring plots could provide reliable trend analyses for numbers of breeding birds at a colony.

Higher burrow density estimates in permanent plots than in transect plots were expected because permanent plots were subjectively placed in higher density areas. Contrary to our expectation, however, estimated burrow densities for Cassin's Auklet on East Copper Island from the two methods converged between 1985 and 2003. There were extensive blowdowns during intervening years that affected much of the colony, including a number of the permanent plots (Lemon 2003). We think that habitat alteration within the permanent plots served to make them more representative of the entire colony, resulting in similar burrow density estimates from the plots and the transect surveys.

Problems repeating and interpreting counts

With few exceptions, corner stakes have remained in place over the 25 years since plots were established, and the mapping and directions recorded have enabled us to relocate all plots in successive years. The biggest challenge to relocating plots has been vegetation changes, such as a thick cover of regenerating conifers in the wake of windfall events, that have obscured stakes.

Most plots contained only one nesting species, but species may have been misidentified in some cases where Cassin's Auklets overlapped with other species. Cassin's Auklet burrows could generally be differentiated by size from larger Rhinoceros Auklet or Tufted Puffin burrows but not from similar-sized Ancient Murrelet burrows (see also Fischer & Griffin 2000). In areas where Cassin's Auklets and Ancient Murrelets overlapped, unique characteristics of feathers, eggshell or egg membrane fragments, faeces and food remains found within the tunnel were used to distinguish species (Rodway *et al* 1988). Identity was assigned to the dominant species when no distinguishing evidence could be found, but this occurred in few cases and was not considered a problem affecting count comparisons. Another difficulty, specific to forested colonies, was identifying the number of individual burrows under complex raised root boles with many openings. We were conservative in deciding how many burrows were present in those situations, tallying only one burrow unless separate tunnels were obvious. We used the same criteria when conducting transect surveys.

For Ancient Murrelet colonies, which have lower burrow density, plots up to 20 × 20 m were required to ensure enough burrows were located within them. By subdividing the plot for purposes of mapping, that size was feasible to survey in the open forests of Haida Gwaii. Where burrows were dense or shrubs and ground cover complex, as in forested Rhinoceros Auklet and Cassin's Auklet colonies, 10 × 10 m plots were practical; we found larger plots too cumbersome to orient within or survey.

Methodological considerations

A main problem with our monitoring scheme is that burrow density estimates from permanent plots are inherently biased because plots were subjectively located in higher-density areas. Some monitoring schemes have distributed permanent plots randomly (Harris & Rothery 1988) or used the "star system" (Anker-Nilssen & Røstad 1993), accomplishing both census and monitoring objectives with unbiased sampling. During inventory surveys in BC, a centred-start, systematic sampling scheme of numerous quadrats distributed along evenly spaced transects (Madow 1953, Nettleship 1976, Savard & Smith 1985) provided unbiased and precise estimates of burrow density within a colony (methods are described in detail in Rodway *et al.* 1988). Our goal for the monitoring scheme was to obtain reliable indicators of population trends rather than unbiased estimates of burrow density or population size. We thus sacrificed representativeness for efficacy to ensure that trends could be detected with a moderate amount of effort, given limited management resources. Permanent plots located in high-density areas have the advantage of greater statistical power to detect trends with fewer plots because each plot contains a large number of burrows. A disadvantage is that trends may not be generalizable if population parameters such as survival and recruitment are density-dependant (Anker-Nilssen & Røstad 1993). However, high-density areas often contain the majority of nesting birds, and trends determined there likely reflect overall population change. Concordance of trends determined from permanent plots and concurrent transect surveys support that premise. Over the long term, there is the additional problem that habitat use is dynamic, and the location of high-density areas may shift (e.g. Rodway *et al.* 2003). It is therefore important to assess changes in distribution. This would be especially true for colonies impacted by or recovering from introduced predators.

A potential source of error common to most monitoring schemes is observer differences in judging what constitutes a burrow. Our definition of a burrow (see Methods) differs from the "apparently occupied burrow" (Evans 1980) commonly used as the counting unit in census and monitoring programs for Atlantic Puffins (Harris & Murray 1981, Anker-Nilssen & Røstad 1993, Walsh *et al.* 1995, Barrett 2001). In those schemes, judgement of apparent occupancy is based on signs of activity at the burrow entrance and can be highly variable among observers. It also varies in relation to time of the nesting season and the activity of birds on the colony (Anker-Nilssen & Røstad 1993). Our criteria for identifying a burrow were less subjective, although burrows can still be missed if they are obscured by vegetation, and, for Ancient Murrelets, a subjective judgement is sometimes required to distinguish a burrow from a plain hole in the ground. We have found that signs of activity, or lack of such signs, at a burrow entrance are often poor indicators of active breeding, especially for Ancient Murrelets. Burrows around tree roots in forested habitat are generally quite stable and may show little sign of refurbishment from year to year. Total burrows is thus an appropriate measure for species and habitats common in BC colonies, and is likely less variable than "apparently occupied burrows" in respect to breeding phenology, rates of nonbreeding or seasonal changes in food supply that affect activity on the colony. Regarding observer bias, we have been fortunate to have the same lead observer (M. Lemon) throughout the history of the BC scheme.

Trends in burrow density indicate trends in population size if we assume that colony area and burrow occupancy rates remain unchanged. One of the main drawbacks to a monitoring scheme for burrow-nesting species using only fixed plots is that, in most cases, no direct information is gathered on colony boundaries or burrow occupancy rates (Evans 1980). Changes in colony boundaries can be readily detected during replicated transect surveys or surveys using the "star system" (Anker-Nilssen & Røstad 1993). An expedient alternative to full-scale surveys is to place permanent markers along transect lines at colony borders from which future measurements can be made to determine changes (e.g. Rodway *et al.* 2003). This should be considered for future colony surveys in BC.

Determining burrow occupancy rates (proportion of burrows in which an egg is laid in the current season) generally requires excavating burrows and disturbing nesting birds, and so is not done within permanent plots. However, occupancy rates for Ancient Murrelets can be reliably determined after adults and chicks have departed so that nesting birds are not disturbed (Gaston *et al.* 1988). Thus, occupancy rates could be determined without excavation or disturbance in cases when burrows were relatively short and plots were surveyed after birds had departed (Lemon 1997, 2003). For other species, separate samples of burrows must be checked during the breeding season to provide burrow occupancy rates.

CONCLUSIONS AND RECOMMENDATIONS

Data from permanent plots have indicated major declines for Cassin's Auklets in their breeding population centre on Triangle Island, and increasing or stable trends for Ancient Murrelet, Rhinoceros Auklet and Tufted Puffins, except on Pine Island where Rhinoceros Auklets showed a declining trend. Declining trends for Cassin's Auklets on Triangle Island are consistent with indications from other studies (Bertram *et al.* 2005), but trends for Ancient Murrelets on monitored colonies contrast sharply with known population declines and abandonment at colonies impacted by introduced rats and raccoons (Gaston 1994). This threat to a majority of the world's Ancient Murrelet population (Rodway 1991) has thus gone undetected by the permanent plot monitoring scheme, because impacted colonies were not included in the sampling regime. This highlights the need for a broad sampling of colonies within the permanent plot scheme and the importance of additional surveillance and study of breeding populations to augment the scheme.

In addition to trends in burrow density, the monitoring plots have provided data on changes in vegetation cover (e.g. Hipfner *et al.* 2010), burrow persistence and predation levels. Habitat changes observed within permanent plots indicate a dynamic colony structure on exposed, forested islands such as Rankine and East Copper. The mosaic of mature forest, windfall areas and different-age, regenerating spruce forests around the perimeter of the islands influence the distribution and density of nesting Cassin's Auklets and other burrowing species. Permanent plots allow us to monitor the recovery and recolonization of habitats impacted by windfall or erosion events (Lemon 2003, 2005). In forested colonies where we can accurately mark the location of burrow entrances in relation to terrain and ground cover features, the fate of individual burrows can be followed through time, providing some insight into burrow use and longevity.

Despite some shortcomings, permanent monitoring plots provide an effective method for detecting trends in seabird populations at colony and regional scales. They are a valuable component of a comprehensive monitoring program that also includes annual productivity and survival studies (Evans 1986). Regional differences in population trends and other breeding parameters (Bertram *et al.* 2005, 2009, Slater & Byrd 2009) make widespread sampling of breeding colonies important. In BC, better regional comparisons would be possible if plots were established in colonies of Ancient Murrelet and Cassin's Auklet on the west coast of Haida Gwaii and of Cassin's Auklet and Rhinoceros Auklet off the central mainland coast. The distribution of permanent plots within colonies and at a coastal scale should be reassessed at regular intervals. Placement of permanent plots in abandoned but historically occupied areas on islands such as Langara would be valuable for monitoring potential recolonization following removal of introduced predators. Province-wide, full-colony transect surveys warrant repeating to re-establish baseline population estimates, better interpret trend information provided by the permanent plots monitoring scheme, and determine the status of numerous colonies not included in the monitoring program.

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REFERENCES

ANKER-NILSSEN, T. & RØSTAD, O.W. 1993. Census and monitoring of Puffins *Fratercula arctica* on Røst, N Norway, 1979–1988. *Ornis Scandinavica* 24: 1-9.

ANKER-NILSSEN, T., ERIKSTAD, K.E. & LORENTSEN, S.-H. 1996. Aims and effort in seabird monitoring: an assessment based on Norwegian data. *Wildlife Biology* 2: 17-26.

BARRETT, R.T. 2001. Monitoring the Atlantic Puffin *Fratercula arctica*, Common Guillemot *Uria aalge* and Black-legged Kittiwake *Rissa tridactyla* breeding populations on Hornøya, northeast Norway, 1980-2000. *Fauna norvegica* 21: 1-10.

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.

BERTRAM, D.F., HARFENIST, A. & SMITH, B.D. 2005. Ocean climate and El Niño impacts on survival of Cassin's Auklets from upwelling and downwelling domains of British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 2841-2853.

BERTRAM, D.F., HARFENIST, A. & HEDD, A. 2009. Seabird nestling diets reflect latitudinal temperature-dependent variation in availability of key zooplankton prey populations. *Marine Ecology Progress Series* 393: 199-210.

BERTRAM, D.F., KAISER, G.W. & YDENBERG, R.C. 1991. Patterns in the provisioning and growth of nestling Rhinoceros Auklets. *Auk* 108: 842-852.

BERTRAM, D.F., MACKAS, D.L. & McKINNELL, S.M. 2001. The seasonal cycle revisited: interannual variation and ecosystem consequences. *Progress in Oceanography* 49: 283-307.

BYRD, G.V. & DRAGOO, D.E. 1997. Breeding success and population trends of selected seabirds in Alaska in 1996. US Fish and Wildlife Service Report AMNWR 97/11. Homer, AK: US Fish and Wildlife Service. 44 pp.

CAMPBELL, R.W., DAWE, N.K., McTAGGART-COWAN, I., COOPER, J.M., KAISER, G.W. & McNALL, M.C.E. 1990. The birds of British Columbia. Vol. II. Nonpasserines: diurnal birds of prey through woodpeckers. Victoria, BC: Royal British Columbia Museum.

CARL, G.C., GUIGET, C.J. & HARDY, G.A. 1951. Biology of the Scott Island group, British Columbia. Victoria, BC: Provincial Museum of Natural History and Anthropology.

CUMMING, R.A. 1931. Some birds observed in the Queen Charlotte Islands, British Columbia. *Murrelet* 12: 15-17.

EVANS, P.G.H. 1980. Auk censusing manual. Aberdeen: The Seabird Group. 13 pp.

EVANS, P.G.H. 1986. Monitoring seabirds in the north Atlantic. In: MEDMARAVIS & Monbailliu, X. (Eds.) Mediterranean marine avifauna. NATO ASI Series, Vol. G12. Berlin: Springer-Verlag. pp. 179-206.

FISCHER, J.B. & GRIFFIN, C.R. 2000. Can burrow-nesting seabirds be identified from their burrow dimensions? *Wildlife Society Bulletin* 28: 586-591.

GASTON, A.J., JONES, I.L. & NOBLE, D.G. 1988. Monitoring Ancient Murrelet breeding populations. *Colonial Waterbirds* 11: 58-66.

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

GASTON, A.J. & LEMON, M.J.F. 1996. A tale of two islands: comparison of population dynamics of Ancient Murrelets at two colonies in Haida Gwaii, Canada. In: Gaston, A.J. (Ed.). Laskeek Bay Research 6. Queen Charlotte City, BC: Laskeek Bay Conservation Society. pp. 29-38.

GASTON, A.J. & MASSELINK, M. 1997. The impact of Raccoons *Procyon lotor* on breeding seabirds at Englefield Bay, Haida Gwaii, Canada. *Bird Conservation International* 7: 35-51.

GASTON, A.J, BERTRAM, D.F., BOYNE, A.W., CHARDINE, J.W., DAVOREN, G., DIAMOND, A.W., HEDD, A., MONTEVECCHI, W.A., HIPFNER, J.M., LEMON, M.J.F., MALLORY, M.L., RAIL, J.-F. & ROBERTSON, G.J. 2009. Changes in Canadian seabird populations and ecology since 1970 in relation to changes in oceanography and food webs. *Environmental Reviews* 17: 267-286.

GJERDRUM, C., VALLEÉ, A.M.J., ST. CLAIR, C.C., BERTRAM, D.F., RYDER, J.L. & BLACKBURN, G.W. 2003. Tufted puffin reproduction reveals ocean climate variability. *Proceedings of the National Academy of Sciences* 100: 9377-9382.

GOLUMBIA, T.E. 2000. Introduced species management in Haida Gwaii (Queen Charlotte Islands). In: Darling, L.M. (Ed.) Proceedings of a conference on the biology and management of species and habitats at risk, Kamloops, B.C., 15–19 Feb. 1999, vol. 1. Victoria, BC & Kamloops, BC: BC Ministry of Environment, Lands and Parks & University College of the Cariboo. pp. 327-332.

HANCOCK, D. 1970. New Rhinoceros Auklet colony for British Columbia. *Condor* 72: 491.

HARFENIST, A. & KAISER, G.W. 1997. Effects of introduced predators on the nesting seabirds of the Queen Charlotte Islands. In: Vermeer, K. & Morgan, K.H. (Eds.) The ecology, status, and conservation of marine and shoreline birds of the Queen Charlotte Islands. Occasional Paper 93. Delta, BC: Canadian Wildlife Service. pp. 132-136.

HARFENIST, A., MACDOWELL, K.R., GOLUMBIA, T., SCHULTZE, G. & LASKEEK BAY CONSERVATION SOCIETY. 2000. Monitoring and control of Raccoons on seabird colonies in Haida Gwaii (Queen Charlotte Islands). In: Darling, L.M. (Ed.) Proceedings of a conference on the biology and management of species and habitats at risk, Kamloops, B.C., 15–19 Feb. 1999, vol. 1. Victoria, BC & Kamloops, BC: BC Ministry of Environment, Lands and Parks & University College of the Cariboo. pp. 333-340.

HARRIS, M.P. & MURRAY, S. 1981. Monitoring of puffin numbers at Scottish colonies. *Bird Study* 28: 15-20.

HARRIS, M.P. & ROTHERY, P. 1988. Monitoring of puffin burrows on Dun, St Kilda, 1977–1987. *Bird Study* 35: 97-99.

HARTMAN L.H. & EASTMAN, D.S. 1999. Distribution of introduced Raccoons *Procyon lotor* on the Queen Charlotte Islands: implications for burrow-nesting seabirds. *Biological Conservation* 88: 1-13.

HARTMAN L.H., GASTON, A.J. & EASTMAN, D.S. 1997. Raccoon predation on Ancient Murrelets on East Limestone Island, British Columbia. *Journal of Wildlife Management* 61: 377-388.

HEDD, A., RYDER, J.L., COWEN, L. & BERTRAM, D.F. 2002. Inter-annual variation in the diet, provisioning and growth of Cassin's Auklet at Triangle Island, British Columbia: responses to variation in ocean climate. *Marine Ecology Progress Series* 229: 221-232.

HEDD, A., BERTRAM, D.F., RYDER, J.L. & JONES, I.L. 2006. Effects of interdecadal climate variability on marine trophic interactions: Rhinoceros Auklets and their fish prey. *Marine Ecology Progress Series* 309: 263-278.

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.

HIPFNER, J.M., LEMON, M.J.F. & RODWAY, M.S. 2010. Introduced mammals, vegetation changes, and seabird conservation on the Scott Islands, British Columbia, Canada. *Bird Conservation International* 20: 295-305.

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. 1992. Survey of permanent seabird monitoring plots in Skincuttle Inlet. In: Gaston, A.J., Lawrence, A. & French, C. (Eds.) Laskeek Bay Conservation Society Report on Scientific Activities in 1991. Queen Charlotte City, BC: Laskeek Bay Conservation Society. pp. 25-28.

LEMON, M.J.F. 1993. Survey of permanent seabird monitoring plots on Ramsay Island. In: Gaston, A.J. & Lawrence, A. (Eds.) Laskeek Bay Conservation Society Report on Scientific Activities No. 3, 1992. Queen Charlotte City, BC: Laskeek Bay Conservation Society. pp. 52-55.

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. 2003. Surveys of permanent seabird monitoring plots on George Island and East Copper Island, Gwaii Haanas National Park, June 2003. Unpublished report to Parks Canada Dec. 2003. Delta, BC: Canadian Wildlife Service.

LEMON, M.J.F. 2005. Surveys of permanent Seabird Monitoring Plots on Rankine Island, Gwaii Haanas National Park, June 2005. Unpublished report to Parks Canada Feb. 2006. Delta, BC: Canadian Wildlife Service.

LEMON, M.J.F. & GASTON, A.J. 2000. Trends in Ancient Murrelet populations in Haida Gwaii since 1980. In: Gaston, A.J. (Ed.) Laskeek Bay Research 9. Queen Charlotte City, BC: Laskeek Bay Conservation Society. pp. 22-26.

MADOW, W.G. 1953. On the theory of systematic sampling, III. Comparison of centered start and random start systematic sampling. *Annals of Mathematical Statistics* 24: 101-106.

NETTLESHIP, D.N. 1976. Census techniques for seabirds of arctic and eastern Canada. Occasional Papers No. 35. Ottawa: Canadian Wildlife Service. 33 pp.

REGEHR, H.M., RODWAY, M.S., LEMON, M.J.F. & HIPFNER, J.M. 2007. Recovery of the Ancient Murrelet *Synthliboramphus antiquus* colony on Langara Island, British Columbia, following eradication of invasive rats. *Marine Ornithology* 35: 137-144.

RODWAY, M.S. 1991. Status and conservation of breeding seabirds of British Columbia. In: Croxall, J.P. (Ed.) Seabird status and conservation: a supplement, ICBP Technical Publication No. 11. Cambridge: 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. 1990a. British Columbia seabird colony inventory: report #2 — west coast Moresby Island. Technical Report Series No. 65. Delta, BC: Canadian Wildlife Service. 163 pp.

RODWAY, M.S., LEMON, M.J.F. & SUMMERS, K.R. 1990b. British Columbia seabird colony inventory: report #4 — Scott Islands. Technical Report Series No. 86. Delta, BC: Canadian Wildlife Service. 109 pp.

RODWAY, M.S. & LEMON, M.J.F. 1990. British Columbia seabird colony inventory: report #5 — west coast Vancouver Island. Technical Report Series No. 94. Delta, BC: Canadian Wildlife Service. 87 pp.

RODWAY, M.S. & LEMON, M.J.F. 1991a. British Columbia seabird colony inventory: report #7 — northern mainland coast. Technical Report Series No. 121. Delta, BC: Canadian Wildlife Service. 182 pp.

RODWAY, M.S. & LEMON, M.J.F. 1991b. British Columbia seabird colony inventory: report #8 — Queen Charlotte Strait and Johnstone Strait. Technical Report Series No. 123. Delta, BC: Canadian Wildlife Service. 82 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.

RODWAY, M.S., REGEHR, H.M. & CHARDINE, J.W. 2003. Status of the largest colony of Atlantic Puffins in North America. *Canadian Field-Naturalist* 117: 70-75.

SAVARD, J-P.S. & SMITH, G.E.J. 1985. Comparison of survey techniques for burrow-nesting seabirds. Progress Note No. 151. Ottawa: Canadian Wildlife Service.

SLATER, L. & BYRD, G.V. 2009. Status, trends, and patterns of covariation of breeding seabirds at St Lazaria Island, Southeast Alaska, 1994–2006. *Journal of Biogeography* 36: 465-475.

SUMMERS, K. & RODWAY, M.S. 1988. Raccoon-seabird interactions (with notes on Rats and Marten) on Moresby Island, Queen Charlotte Islands: a problem analysis [unpublished report]. Smithers, BC: Ministry of Environment and Parks. 62 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.

WALSH, P.M., HALLEY, D.J., HARRIS, M.P., DEL NEVO, A., SIM, I.M.W. & TASKER, M.L. 1995. Seabird monitoring handbook for Britain and Ireland. Peterborough, UK: JNCC / RSBP / ITE / The Seabird Group.