

Monitoring Ancient Murrelet Breeding Populations

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Abstract.—We examined methods for monitoring changes in Ancient Murrelet populations. Physical examination of burrows, the normal procedure for determining occupancy in most burrow-nesting seabirds, was found to cause frequent desertions. As deserted burrows were less likely than successful burrows to be occupied in subsequent years, we do not consider this method suitable for long-term population monitoring. We suggest either (1) inspecting burrows after the chicks have departed, at which time the remains of egg membranes give an accurate indication of successful breeding, or (2) using knock-down tags to monitor occupancy and catching chicks en route to the sea to monitor productivity. We did not find counts of vocalizations or arrivals at the colony to have any value for monitoring because of the extreme night-to-night variation. Nor did we find an optic-fibrescope or a telethermometer to be of any value in determining burrow occupancy.

Key words.—Ancient Murrelet, censusing, monitoring, *Synthliboramphus antiquus*.

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Ancient Murrelets breeding in the Queen Charlotte Islands of British Columbia, Canada nest in colonies of from a few hundred to about 70 000 pairs on forested islands. They dig burrows in soft soil, often placing the entrance among tree roots or boulders (Vermeer and Lemon 1986). Although several problems involved in censusing and monitoring Ancient Murrelets are common to most burrow-nesting seabirds, there are some unique aspects relating to their unusual biology. Two eggs are laid with an interval of about 8 days. Incubation begins soon after the clutch is complete and both eggs normally hatch within 24 h of one another (Sealy 1976). The chicks are not fed in the burrow, but leave with their parents within 4 days and all subsequent development takes place at sea.

We studied the reproductive ecology and behaviour of Ancient Murrelets at Reef Island in the Queen Charlotte Islands archipelago over three seasons (1984-1986) to evaluate different methods for monitoring and censusing the species. We examined the following monitoring techniques: Counting burrows; determining occupancy by examining burrows for signs of occupation; determining occupancy from the frequency with which tags were displaced from burrow entrances; counting vocalizations; playing back recordings of vocalizations at burrow entrances; counting arrivals; trapping chicks making their way to the sea.

Censuses of Ancient Murrelets can be accomplished by sampling burrow density

using random or evenly spaced quadrats (Savard and Smith 1985). However, determining the proportion of burrows actually occupied is a potential problem. The techniques that we evaluated for monitoring can also be applied to censusing. To examine variation in occupancy rates we compared occupancy on different parts of the colony and also looked at the same plot in different years.

STUDY AREA

Reef Island (52° 52' N, 131° 31' W) is situated 8 km east of the main Queen Charlotte Islands archipelago. It is 4 km in length and 2 km at the broadest point (Figure 1). Most of the island is covered with evergreen coastal rainforest (*Picea sitchensis*, *Tsuga heterophylla*, and *Thuja plicata*). Ancient Murrelet burrows are situated almost exclusively in areas of large trees and a closed canopy. The majority occur in a belt along the steeply-sloping north coast of the island (Fig. 1). The forest floor in most areas occupied by murrelets supports only mosses and sparse shrub vegetation, but in a few places, where the canopy is broken, burrows occur among grass tussocks. The latter habitat is more typically occupied on Reef Island, and elsewhere in the Queen Charlotte Islands, by Cassin's Auklets (*Ptychoramphus aleuticus*) (Vermeer and Lemon 1986).

METHODS

Observations were made from 12 April to 23 June 1984, from 7 April to 16 June 1985 and from 10 May to 16 June 1986. In 1984 as many burrows as possible were located in three study areas (A, D and F, Fig. 1). Tunnels were dug to give access to nest-chambers where these were not accessible via the entrance and entrances were marked with numbered metal or plastic markers nailed to adjacent roots or trunks. One or more small plastic strips, 1 cm x 5 cm (tags) were

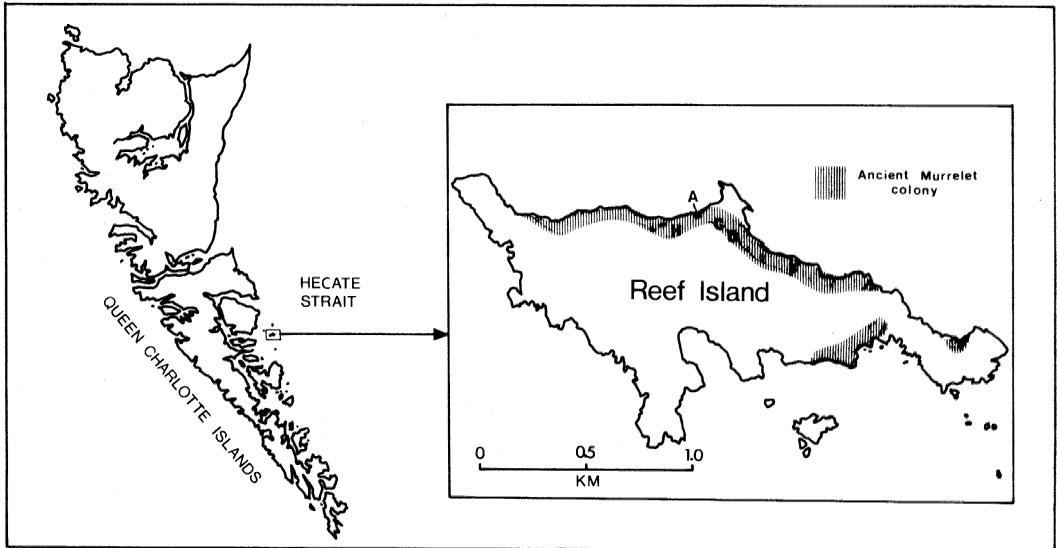


Figure 1. Map showing the position of Reef Island, the distribution of breeding Ancient Murrelets and the location of the study areas mentioned in the text.

loosely erected in the mouth of each burrow so that any bird entering or leaving would displace them.

On areas A and D all likely looking burrows were marked and tagged, but on area F only those containing eggs were so treated. Study burrows were checked daily for the presence or absence of eggs and/or incubating adults and any displaced tags were reset. In area A 20 artificial burrows about 30 cm long were dug on 23 April and thereafter checked in the same way as the natural burrows.

In mid-May, after all laying had been completed, areas A and D and an additional area (H) were surveyed by an observer familiar with Ancient Murrelet burrows, but with no experience of the areas concerned. His results were compared to the sample of burrows selected at the outset.

In June, when most breeders had departed, we re-examined all burrows and recorded evidence of occupation in the form of egg-shell and egg membranes. We also recorded the presence of scuff-marks at the entrance and feathers or droppings in the tunnel or nest chamber. Within each study area we selected one 25 x 25 m plot, which we divided into a grid of 5 x 5 m quadrats. The position of each burrow was mapped within this grid.

At another plot (C) no examination of burrows was carried out and no disturbance caused apart from placing tags in all burrow mouths. Nightly observations were made on this plot by an observer sitting in a canvas blind at the lower end of the plot who recorded all arrivals, departures and calls heard on the plot, or (separately) beyond its boundaries. These activities were recorded for the first 100 min (1984) or 150 min (1985) of murrelet activity each evening (Jones 1985).

Five experiments, each involving ten burrows in which incubating birds were known to be present, were performed to test whether the birds could be induced to respond to calls replayed at the mouth of the burrow. In each case the first 5s of calling during an arrival at an occupied burrow was replayed on one

tape recorder via a battery-powered speaker, while a second machine recorded any sounds coming from the burrow via a microphone placed a few inches down the tunnel. A different recording was used for each series of playbacks (Jones 1985).

In 1985 procedures were similar to 1984 with the following exceptions; plot A was not used, artificial burrows were dug on plots D and F, and tag knock-downs were recorded for unoccupied as well as occupied burrows at plot F. In 1986 the same procedures were used as in 1985, except that the watches on plot C and the burrow examination at the end of the season were not carried out. In 1984 we used an optic fibrescope (medical gastroscope) and a telethermometer (Yellow Springs Instruments) to examine burrows where we had previously established the presence or absence of a sitting bird. This enabled us to evaluate the potential of these instruments for improving our ability to determine whether or not burrows were occupied.

When the chicks leave their burrows they make their way to the shore alone and rendezvous with their parents through mutual recognition of calls (Jones et al. in press). If they encounter obstacles they attempt to find a way around them, taking the direction closest to their preferred heading. We made use of this behavior to catch chicks by setting up fences of clear plastic sheets, running diagonally across the direction of slope. These funnelled the chicks into pens close to the shore where they were easily captured, banded and released to the sea. A similar technique for catching fledgling Atlantic Puffins (*Fratercula arctica*) was described by Nettleship (1969). No chick was held for more than 5 min.

In 1985 we conducted a census of the entire island, using a grid of evenly spaced quadrats. All burrows found were examined for occupancy. Details of the census are not given here, but we use information on the proportion of deserted clutches among burrows examined during the census to provide information on desertion rates in undisturbed parts of

the colony. We compared the proportion of apparently deserted burrows in our census with the proportion of burrows on our study plots where the pair deserted after only one inspection. Disturbance involved feeling under the sitting bird to verify clutch size and in some cases the removal of the eggs for measurement. No adults were grasped or removed from the burrows. We assume that examination of burrows when no birds were present had negligible impact.

To analyse the data from the tag knock-downs we divided the breeding season into three periods, defined as follows: laying period—from the date at which 10% of clutches were complete to the date when 90% were complete; incubation period—from the end of the laying period to the date when 10% of clutches had hatched; departure period—from the end of the incubation period to the date by which 90% of broods had departed. In 1984 the laying period ran from 23 April to 6 May, incubation from 7 to 25 May and departure from 26 May to 8 June. In 1985 laying was from 14 April to 5 May, incubation from 6 to 16 May and departure from 17 May to 8 June. In 1986 incubation was from 11 May (start of observations) to 19 May and departure from 20 May to 7 June.

RESULTS

Counting Burrows

Initially 35 burrows were located and marked on plot A and 29 on plot D. The survey carried out in mid-May 1984 located a further 5 burrows on plot A and a further 8 on plot D. In 1985 a similar mid-season survey on plot D located 4 more occupied burrows that all showed evidence of occupation in earlier years. The mid-season survey in 1984 found evidence of previous occupation (eggshell, egg membrane) in only 14 of the burrows initially located on plot A and 25 of those located on plot D.

Some burrows were missed initially because their mouths were blocked by twigs, apparently pulled into the entrance by the occupants. After we discovered this habit we found that it occurred regularly at about 5% of burrows, usually those where the nest chamber was close to the burrow entrance. Similar behaviour by Ancient Murrelets has been noticed by M. Lemon and M. Rodway (pers. comm.) at other colonies.

A few burrows have more than one potential nest chamber and in one case two chambers were occupied in the same year. Conversely, several nest chambers had more than one entrance. However, to a close approximation, a count of burrow

entrances was equivalent to a count of potential nest sites.

Direct Examination

Before deciding whether a burrow is occupied we must first decide whether it constitutes a potential breeding site for an Ancient Murrelet. Practically all Ancient Murrelet burrows on Reef Island had entrances less than 25 cm in diameter, tunnels more than 40 cm long, and an enlarged nest-chamber. In most cases the incubating bird was invisible from the entrance because of bends in the tunnel. However, one site on plot F in 1984 was in an apparently natural, shallow cavity at the base of a tree. The sitting bird was visible from several metres away. Similar sites occur occasionally on other colonies (M. Lemon and M. Rodway, pers. comm.). Several sites were situated in hollow chambers within the base of trees, connected to the exterior by short tunnels of less than 20 cm.

In a few areas of Reef Island the nesting habitat of Ancient Murrelets overlapped that of Cassin's Auklets, which use similar sized burrows, but generally prefer sites beneath grass tussocks (Vermeer and Lemon 1986). Cassin's Auklet burrows could usually be distinguished by their characteristic fishy odour (no fishy smell was detectable at Ancient Murrelet burrows), and by whitish streaks of defecation at the entrance.

Variation in the physical structure of the site makes it difficult to define precisely what constitutes a burrow. We followed the procedure adopted by other Canadian Wildlife Service teams in regarding as burrows only those which showed unequivocal evidence of present or past occupation by murrelets, in the form of eggshell fragments, pieces of old egg membrane, nest cups, or feathers. In the Ancient Murrelet the egg membrane at hatching is very thick and persistent, and hence provides a particularly good clue to previous use. For monitoring purposes it is not important exactly what criteria are used, provided that they are clearly defined and uniformly applied.

At plot A only 9 (22%) and at plot D 12 (32%) nest chambers could be reached by stretching an arm through the entrance. For the remainder one or more ac-

cess tunnels had to be dug. Even then 9 (22%) nest chambers on plot A and 2 (5%) on plot D could not be reached by any means. The high proportion of inaccessible nest chambers on plot A was due to the fact that many burrows were situated among large boulders.

We found it impossible to determine occupancy for burrows where we could not reach the nest chamber. The optic fibre-scope provide a good view of the interior of the burrow, but could not be inserted beyond arm's reach, hence it improved our ability to inspect burrows only marginally. Temperature readings made at occupied burrows with the telethermometer showed that no difference in temperature could be detected unless the probe was held within 3 cm of the bird, making it valueless for determining occupancy. Likewise, no visible feature of the burrow (scuff marks, feathers or droppings) was found to relate to occupancy, presumably because non-breeding prospectors may wander into any burrow or other cavity.

Occupancy Rates

Considering only burrows where occupancy could be definitely determined, the occupancy rate at plot A was significantly lower than at plot D in 1984 (Table 1). In 1985 occupancy was similar on plots D and F and the density of burrows on our 25 x 25 m plots was identical (312 burrows/ha). Plot D, the only one surveyed in all three years, showed no significant inter-year variation, although occupancy declined somewhat, perhaps because of our activities (see below).

Table 1. Occupancy rates of natural Ancient Murrelet burrows on different plots and in different years.

Plot	Year	Total burrows	Occupied Burrows	Occupancy (%)
A	1984 ¹	18	2	11
D	1984	28	20	71
H	1984	6	2	33
D	1985	33	19	58
F	1985	28	18	64
D	1986	28	14	50

¹Comparing plots for 1984, $\chi^2 = 17.75$, $P < 0.001$

Tag Knock-downs

During incubation members of Ancient Murrelet pairs exchanged incubation duty every 1-6 days (Mean; 1984 3.11 days, 1985 2.31 days, unpublished data based on observations of marked birds). Tags were knocked down at occupied burrows more frequently than incubation changes occurred, by roughly 50%. Day to day variation throughout the season was considerable (Fig. 2). Knock-downs at occupied burrows were approximately twice as frequent as at unoccupied burrows (Table 2).

The frequency with which tags were knocked down at active burrows was consistently higher at plot F than at plot D (Table 2). Tags at artificial burrows in 1985 were also knocked down more frequently at plot F than at plot D, although in both areas there were fewer knock-downs at artificial burrows than at unoccupied natural burrows. Similarly, in 1984 knock-downs were less frequent at artificial burrows than a unoccupied natural burrows on plot A.

Knock-downs at active burrows were significantly more frequent during the lay-

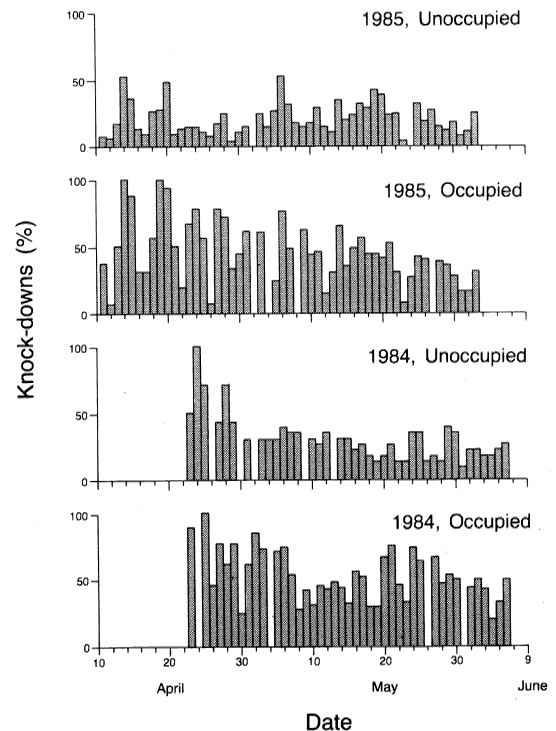


Figure 2. Day to day variation in the proportion of burrows entered in 1984 and 1985.

Table 2. Proportions of burrows where knock-downs occurred at plots D and F, in relation to occupancy and stage of breeding (means of nightly proportions).¹

Year	Burrow status	Laying		Incubation		Departure	
		D	F	D	F	D	F
1984	Occupied	74%(22) ²	* 81%(24)	37%(22)	* 53%(24)	29%(22)	45%(24)
	Unoccupied	44%(7)		20%(10)		21%(10)	
	Duration	14 days		19 days		14 days	
1985	Occupied	56%(16)	* 71%(13)	45%(21)	* 76%(24)	29%(27)	* 52%(30)
	Unoccupied	10%(17)	* 32%(11)	16%(17)	* 38%(11)	15%(17)	29%(11)
	Artificial	2%(20)	12%(20)	0%(20)	* 24%(20)	3%(20)	8%(20)
	Duration	22 days		11 days		23 days	
1986	Occupied			43%(23)	55%(35)	35%(23)	38%(35)
	Unoccupied			16%(23)	32%(24)	18%(23)	19%(24)
	Duration			9 days		19 days	

¹Values separated by an asterisk differ significantly; binomial probabilities <0.01

²Figures in brackets give the number of burrows checked daily

ing period than during the departure period in 1984 at both D and F (D; $\chi^2 = 7.36$, $P < 0.01$; F $\chi^2 = 4.67$, $P < 0.05$). No other samples differed significantly between stages of the breeding season. However, trends in 1985 and 1986 were similar to that seen in 1984, with the frequency of knock-downs diminishing as the season progressed.

Vocalizations and Arrivals

Ancient Murrelets produce a wide variety of vocalizations, but the majority heard outside the burrow can be classified into two types; (1) the 'chirrup', a short, abrupt call and (2) the song, a longer vocalization made up of several distinct elements and conforming to a recognisable pattern (Jones 1985). Both types of vocalizations were heard throughout the season. Their frequency varied enormously; on some nights no calls were heard, while on others more than 200 were recorded in the first 100 min. (Fig. 3). Variation among nights in the number of birds arriving on plot C was similar to variation in vocalizations, although not quite as extreme. The two variables were significantly correlated (Spearman rank correlation coefficients: 1984, $R = 0.809$, $P < 0.005$; 1985, $R = 0.689$, $P < 0.005$).

To compare the usefulness of chirrup calls, arrivals and knock-downs for monitoring changes in the number of Ancient Murrelets using a particular area we used data obtained on plot C during incubation in 1985. Figure 4 plots the coefficient

of variation for each parameter for different sample sizes. On this criterion calls were the most variable and knock-downs the least. For 7-day samples we could not hope to detect a between-year reduction in calls of less than 80%. The corresponding figures for arrivals and knock-downs were 40% and 25% respectively, assuming that variances would not differ among years. The accuracy of these indices is only slightly improved by continuing observations for more than 9 nights.

Playback of Calls

No responses were obtained from the playbacks, except in one case, where a brief response was obtained from the burrow in which the recording had been made. This suggests that the bird in the burrow responded to a call that it recognised individually. The absence of calls at other burrows indicates that calls of unknown individuals do not stimulate a response.

Trapping Chicks

Chicks observed with a nightscope after release from our trapping funnels were seen reuniting with their presumed parents on several occasions. We therefore believe that the capture process did little to disrupt normal departure. In 1986, when three capture funnels were operated throughout the night during the period of departures (12 May-16 June), 710 chicks

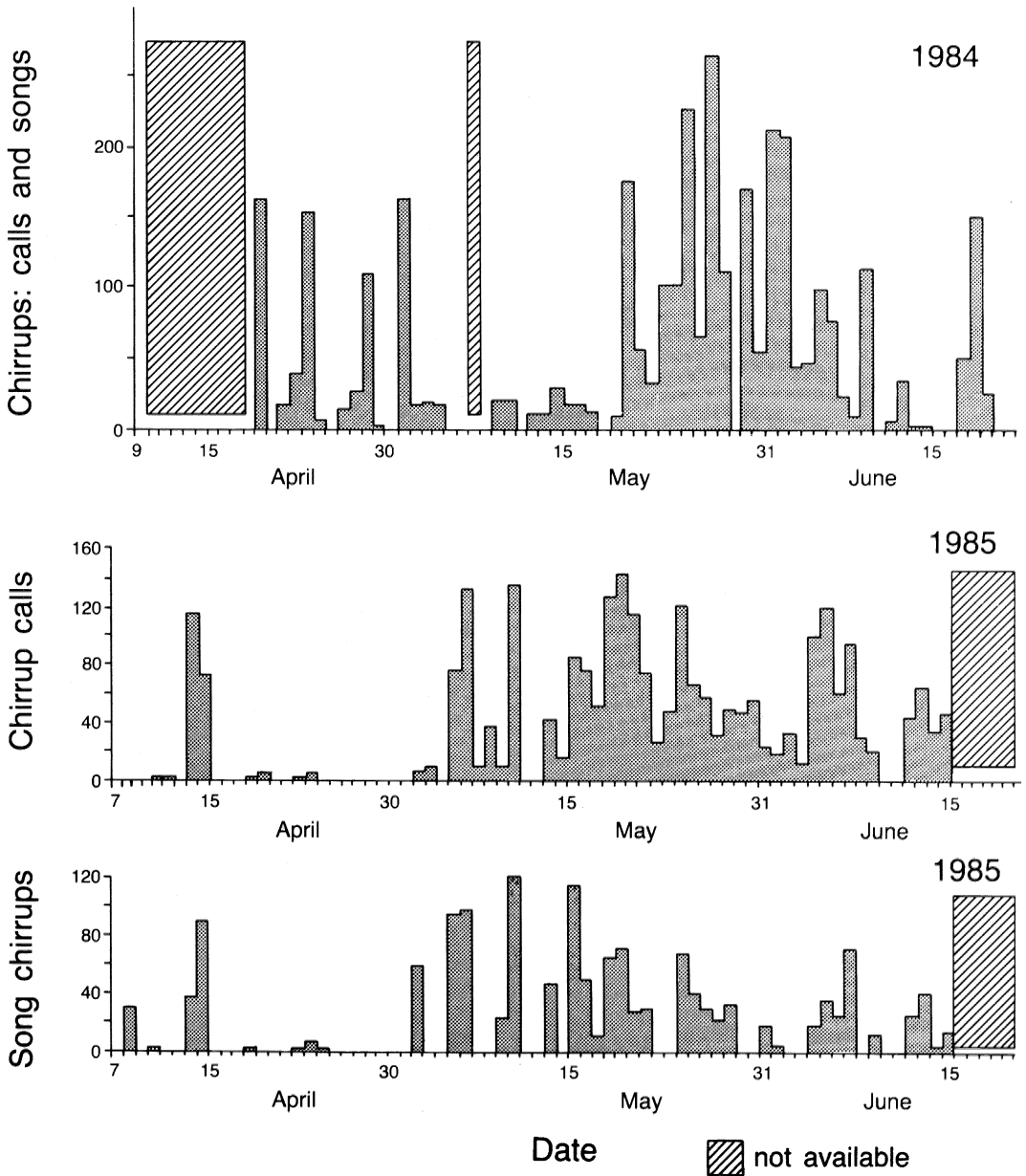


Figure 3. Numbers of songs and chirrup calls heard at plot C in 1984 and 1985.

were captured. From our 1985 census we estimated that the catchment area of our traps contained 500-700 burrows, with an occupancy of 63% (AJG unpubl.). Mean brood size at departure was 1.82 (n=22). Hence the maximum estimate for the number of burrows yields a likely production of 803 chicks. From these figures we believe that our traps caught practically all the chicks originating in the area above them.

Burrow Examination

Among 41 census burrows showing evidence of definite occupancy only two were probably deserted; one containing two cold eggs and another containing evidence that mice had destroyed the eggs. On our study plots most eggs eaten by mice had previously been deserted. If three burrows containing single eggs, perhaps incomplete clutches, are omitted, the desertion

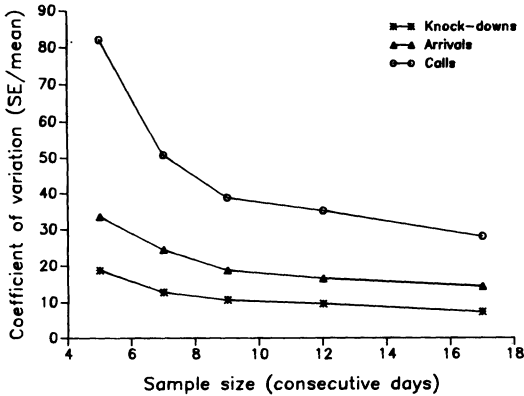


Figure 4. Coefficient of variation (s.e./mean) for calls, arrivals and knock-downs during the 1985 incubation period in relation to sample size.

rate for complete clutches was not more than 5.3% up to the date of our inspection. On plots D and F 10 out of 47 burrows (21%) were deserted after our first examination ($\chi^2 = 3.22, 0.1 > P > 0.05$), suggesting that a single inspection was sufficient to increase the chance of desertion.

Burrows deserted after a single inspection on the study plots had, in most cases, only just begun incubation. For this reason they may have been more susceptible to disturbance than a random sample of burrows visited for monitoring purposes in mid-season. However, in 1985 access tunnels had been dug to all nest chambers prior to laying to facilitate inspection. Consequently there was no cause for the extensive digging often necessary when a burrow is first located. We conclude that surveys involving only a single visit to each burrow may still have a significant impact on reproductive success.

Reproductive Success and Occupancy

We compared the occupancy of burrows with breeding success in the previous year. Among burrows where chicks were reared in 1984 83% ($N=12$) were occupied again the following year, compared to 59% ($N=37$) of unsuccessful burrows. The corresponding figures for 1985 were 83% ($N=23$) and 56% ($N=36$). Combining the two years, which did not differ significantly, shows that unsuccessful sites were significantly less likely to be occupied the following year than successful sites. In a few cases eggs or chicks in our study burrows were depredated before the parents

deserted (1984, 5 cases; 1985, 6 cases; 1986, 1 case). All other failures were due to desertion.

Occupancy after Departure

When burrows were examined at the end of the season in 1984 and 1985 all those from which chicks had successfully departed (17 in 1984, 23 in 1985, including some from areas other than A, D and F) contained large fragments of fresh egg membrane, conspicuously white in color. Most also contained pieces of fresh eggshell, but this was usually broken into small fragments. Egg membranes were also found in 3 of 16 burrows from which eggs had been depredated. Large fragments of eggshell were found in 12 of these. In the three cases where membranes were present the eggs had been pipping when predation occurred. The eggshells with them showed the tooth-marks of mice. Fresh egg membranes were not found in any other burrows. We conclude that successful burrows can be readily identified after the chicks have departed.

DISCUSSION

Ideally a monitoring method should (a) provide an accurate index of population trends, (b) be quick to carry out, (c) be readily transferable between different workers and (d) cause negligible disturbance to breeding birds. The first two criteria involve a trade-off because for most methods the accuracy increases with an increased investment of people and time. We shall discuss the techniques that we tested in the light of these criteria.

Direct Inspection

Direct inspection of burrows is the normal method used to census and monitor burrow-nesting seabirds (e.g. Nettleship 1976). In the case of the Ancient Murrelet, and probably some other species, this method suffers from several drawbacks: (1) It is hard to exactly define what constitutes a burrow, reducing repeatability; (2) In certain areas many nest-chambers are impossible to inspect, causing possible bias in estimates of occupancy; (3) Determining occupancy by digging access holes and reaching into nest chambers may cause de-

sersion and lower the chances that the burrow will be used subsequently; and (4) The method is labour-intensive.

Because finding whether burrows are occupied takes much longer than simply counting them, it is customary for occupancy to be determined for a sub-sample of the burrows counted. The inter-plot variation in occupancy rates observed at Reef Island suggests that where this is done it is important to ensure that occupancy is determined for a random sample of burrows, rather than for a single discrete area. Regretably, we concluded that the use of a fibroscope or telethermometer did not significantly improve our ability to determine occupancy, although the fibroscope might, in some cases, speed it up somewhat. We concluded that, among the methods we tried, the only way to know for certain whether a burrow was occupied was to see or feel a bird, egg or chick.

If burrow examination is considered desirable then we recommend that examination be made after the majority of chicks have departed. Our results suggest that practically all burrows from which chicks have departed successfully, or where eggs have been depredated by mice, can be identified on the basis of eggshell and membrane remains. Most fresh egg membranes look clean and white for at least three weeks after the chicks have left. Membranes from previous years are usually stained brown by humus. Occasionally membranes found on the surface may be hard to identify because they have dried out and curled up. Potentially, the main source of error in this method involves eggs which disappear from burrows without leaving any remains. Our results suggested that the proportion of clutches that disappeared in this way was less than 5%. The proportion might be even lower in an undisturbed colony. We believe that, given the possible errors inherent in other methods, this limitation is acceptable.

Knock-down Tags

Although we were unable to distinguish occupied from unoccupied burrows on the basis of knock-downs, the substantial difference in mean knock-down frequencies allows an index of occupancy to be obtained for a sample of burrows. The method is very quick to set up and check

and causes little disturbance. Consequently, we judge that records of knock-downs obtained for the same areas over the same dates in successive years provide a potential monitoring method, particularly where it is important to keep disturbance to a minimum.

Observations of marked pairs showed that the maximum length of incubation shifts at Reef Island was five days (AJG, DGN unpubl.). During the pre-laying period all active burrows were entered at least once every five days. Consequently, before the start of chick departures, any burrow where tags are not displaced for six or more consecutive days can be assumed to be inactive. This enables us to estimate a 'maximum occupancy'; the proportion of burrows where no period of more than five days elapsed between knock-downs.

The difference in the frequency of knock-downs observed between areas D and F suggests that comparisons between different areas by this method might be misleading. For long-term monitoring of occupancy rates it would probably be wise to use several different sample areas.

Deer Mice (*Peromyscus* sp.) are abundant on Reef Island and certainly use some of the Ancient Murrelet burrows from time to time, because spruce cones gnawed in characteristic fashion are often found in the tunnels. Two observations suggested that the mice hardly ever displaced our tags. First, knock-downs declined virtually to zero once the majority of Ancient Murrelet activity had ceased at the end of the season. Second, some unoccupied burrows which contained large stores of cones, presumably accumulated by mice, registered no knock-downs. Our tags were large and conspicuous and were probably avoided by the mice. Their activities might have been more of a problem had we used tooth-picks or twigs.

Vocalizations

Because of the great night-to-night variation in the frequency of calling above ground we do not consider counting calls to have any value for monitoring. In areas where burrows occur at low density and in scattered pockets, listening for calls may provide a useful clue to the presence of Ancient Murrelets. However, no potential

breeding area can be dismissed on the basis of a single night's observations. Likewise, playback appears to have little application in determining burrow occupancy for Ancient Murrelets, in contrast to its successful use with Storm-Petrels (James 1984).

Trapping Chicks

This technique is useful for banding chicks with the minimum of disturbance. For monitoring it has the additional advantage of being easily replicated, provided that the position of fences is clearly marked so that they can be set in exactly the same places in successive years. If the traps are operated nightly throughout the departure period of about one month a good index of productivity for that year can be obtained. Because the departure dates of Ancient Murrelets are approximately normally distributed (AJG unpublished), captures over any period which includes the peak can be extrapolated to yield an estimate of the total number of chicks departing. By using knock-down tags and chick traps together two important parameters, occupancy and productivity, can be monitored without an arm ever being inserted into a burrow. Such a scheme would probably benefit the birds and would certainly make life easier for the biologists.

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