The Condor 108:423–434

COLONY MAPPING: A NEW TECHNIQUE FOR MONITORING CREVICE-NESTING SEABIRDS

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Abstract. Monitoring populations of auklets and other crevice-nesting seabirds remains problematic, although numerous methods have been attempted since the mid-1960s. Anecdotal evidence suggests several large auklet colonies have recently decreased in both abundance and extent, concurrently with vegetation encroachment and succession. Quantifying changes in the geographical extent of auklet colonies may be a useful alternative to monitoring population size directly. We propose a standardized method for colony mapping using a randomized systematic grid survey with two components: a simple presence/absence survey and an auklet evidence density survey. A quantitative auklet evidence density index was derived from the frequency of droppings and feathers. This new method was used to map the colony on St. George Island in the southeastern Bering Sea and results were compared to previous colony mapping efforts. Auklet presence was detected in 62 of 201 grid cells (each grid cell = 2500 m^2) by sampling a randomly placed 16 m^2 plot in each cell; estimated colony area = 155 000 m^2. The auklet evidence density index varied by two orders of magnitude across the colony and was strongly correlated with means of replicated counts of birds socializing on the colony surface. Quantitatively mapping all large auklet colonies is logistically feasible using this method and would provide an important baseline for monitoring colony status. Regularly monitoring select colonies using this method may be the best means of detecting changes in distribution and population size of crevice-nesting seabirds.

Key words: Aethia pusilla*, Bering Sea, colony mapping, crevice-nesting seabird, Least Auklet, population monitoring.*

Mapeo de Colonias: una Nueva Técnica para el Monitoreo de Aves Marinas que Nidifican en Agujeros

Resumen. El seguimiento de las poblaciones de especies del género *Aethia* y de otras aves marinas que anidan en agujeros ha sido problemático a pesar de que numerosos métodos se han evaluado desde mediados de la década de 1960. La cuantificación de los cambios en la extensión geográfica de las colonias de especies del género *Aethia* podría ser de utilidad como una alternativa que no requiere medir directamente el tamaño poblacional. Se describe un método estandarizado para el mapeo de colonias utilizando una prospección sistemática de cuadrículas aleatorias. El monitoreo consta de dos componentes: una prospección simple de presencia/ausencia y una prospección de la densidad de rastros de las especies de *Aethia* mediante un índice cuantitativo derivado de residuos fecales y/o plumas. Los resultados del mapeo de la colonia en la Isla San Jorge, ubicada en el sureste del Mar de Bering, usando este nuevo método, fueron comparados con los intentos previos de mapear las colonias. Dentro de círculos de 16 m^2 colocados aleatoriamente en la colonia, se detectó la presencia de especies del genero *Aethia* en 62 de un total de 201 cuadrículas (tamaño de la cuadrícula = 2500 m^2; area estimada de la colonia = 155 000 m^2). El índice de densidad de rastros en la colonia de *Aethia* varió en dos órdenes de magnitud. El índice de densidad de rastros y los promedios de conteos repetidos de aves que se encontraban socializando en la superficie de la colonia estuvieron fuertemente correlacionados. El mapeo cuantitativo de grandes colonias de *Aethia* utilizando este método es logísticamente factible, y podría proporcionar una base importante para el monitoreo de la condición de las colonias de *Aethia* a lo largo del tiempo. Realizar monitoreos a largo plazo de colonias específicas usando este método podría ser la mejor solución para detectar cambios en la distribución y el tamaño de las poblaciones.

Manuscript received 12 April 2005; accepted 20 January 2006.
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INTRODUCTION

Global warming and decadal-scale climate oscillations can have profound impacts on the trophic structure of the Bering Sea ecosystem (Hunt et al. 2002). Auklets are specialist predators of small zooplankton, in particular copepods and euphausiids (Hunt et al. 1998), which play a pivotal role in this ecosystem (Springer and Roseneau 1985). As such, auklets are an integral part of the Bering Sea food web and potentially valuable indicators of changes in the trophic structure of this system. Their gregarious behavior, concentrating almost the entire population into a few large colonies, also makes auklets susceptible to catastrophic anthropogenic events such as oil spills and introductions of mammalian predators onto nesting islands.

Least and Crested Auklets (*Aethia pusilla* and *A. cristatella*) are small, crevice-nesting seabirds that breed in often massive colonies on islands in the Bering Sea, Sea of Okhotsk, and Aleutian Islands. The two species occur together on 17 islands in Alaska, as well as many colonies in Russia. Although they are two of the most abundant seabirds in Alaska (Stephensen and Irons 2003), they nest in concealed breeding sites in rock crevices, making them difficult to count. Auklet populations have been described as "impossible to estimate and difficult to exaggerate" (Gabrielson and Lincoln 1959). Since then, population estimates for any auklet colony have been few and largely conjectural, sometimes varying by an order of magnitude (Shuntov 1999). The uncertainty regarding population size and trends is due largely to problems of estimating auklet numbers at colonies and to the tremendous number of birds in many colonies.

Monitoring numbers of Least and Crested Auklets at colonies has proven problematic even though numerous methods have been tried since the 1960s (Jones 1993a, 1993b). During the breeding season, adults are typically present on land during two daily activity periods (morning and evening) when they socialize above their nesting crevices (Jones 1993a, 1993b). The most common census technique has been replicated counts of birds attending the surface ('surface counts') in index plots by observers or through time-lapse photography (Bédard 1969, Byrd et al. 1983, Piatt et al. 1990, Jones 1992, Gall 2004). A variation, called 'net-movement', involves counting birds arriving at and departing the colony (Byrd et al. 1983, Craighead and Oppenheim 1985). This technique relies on all nesting birds trading incubation or brooding duties daily, which we now know is not always the case (Fraser et al. 2002). Furthermore, the net-movement technique requires the full attention of an observer for each plot, making it difficult to implement in more than a few plots. Mark-resighting methods have been used to compare numbers of birds attending the surface to the number of birds living in a small plot (Jones 1992, Gall 2004).

No monitoring method has proven satisfactory; all require intensive work in a small plot (or plots) and questions of utility remain due to the high variability of resulting counts. Jones (1992) showed that auklet surface counts varied within and among breeding seasons by up to a factor of two between successive years with no measurable change in population size. Moreover, while surface counts may detect large changes in local density over time, they do not necessarily reflect trends in colony abundance, as colony extent can change independently of breeding crevice density. For example, declining numbers in Atlantic Puffin (*Fratercula arctica*) colonies have occurred through contraction of colony area, not colony density (Ashcroft 1976).

Dovekies (*Alle alle*) and Atlantic Puffins are cavity-nesting seabirds posing similar sampling challenges in the Atlantic. Studies of these species have estimated population sizes by estimating colony surface area and mean density of surface-attending birds (Dovekies: Kampp et al. 2000, Egevang et al. 2003) or mean density of nesting crevices (puffins: Anker-Nilssen and Røstad 1993).

Several reports show that some auklet colonies have decreased in geographic extent or disappeared over a period of decades (e.g., Kiska Harbor, Bent 1912; Bobrof Island, Murie 1959; St. George Island, Roby and Brink 1986; Sirius Point, Kiska Island, ILJ, unpubl. data; Buldir Island, HMR, unpubl. data). These changes are typically interpreted as resulting from vegetation growing around the colony edges and blocking crevice access. Vegetation encroachment appears to be a potential threat to many auklet colonies (Roby and Brink 1986), and likely occurs over a period of decades. However, new auklet habitat can be created by coastal erosion, rockfall, or volcanic eruptions. Auklets have twice been recorded colonizing newly created habitat (Kiska Island, St. George Island; GVB, unpubl. data).

Changes in colony extent or density of breeding birds are likely to occur independently and understanding population change requires a measure of both. Although delineating areas occupied by breeding birds might provide a useful alternative to surface counts for long-term monitoring of auklet colonies, no quantitative, standardized surveys of colony extent have been published from any location. Previous area estimates rarely referenced geographic coordinates or defined a standardized scale for measuring auklet colony extent (which might not be obvious in patchy habitat; Bédard 1969, Hickey and Craighead 1977).

Due to the remote locations of almost all auklet colonies, visits are typically short and infrequent. Therefore, a quick, reproducible monitoring technique is required. The survey design should also be flexible to adapt to differing colony sizes. In this paper, we present and evaluate such a method for quantitatively estimating the extent of and relative density within colonies of crevice-nesting seabirds. In 2004 we tested the technique at Ulakaia Ridge on St. George Island in the Pribilofs, a Least Auklet colony with a long study history including established attendance monitoring plots, a current mark-resight study to estimate adult survival, and previous estimates of both population size (Gabrielson and Lincoln 1959, Craighead 1977, Craighead and Oppenheim 1985) and colony area (Hickey and Craighead 1977, Harding 2003). It has been suggested that the population on St. George has declined by an order of magnitude since 1900 (Roby and Brink 1986). The objectives of our study were to: (1) map the extent of the Ulakaia colony used by nesting auklets in 2004 and compare our results with prior qualitative estimates, and (2) evaluate an index of relative density for the entire colony and compare it to replicated surface counts in the existing attendance plots.

METHODS

FIELD SURVEY

Presence/absence survey. Aerial photographs and previous mapping efforts (Harding 2003) were used to identify an area likely to encompass all potential nesting habitat. We outlined this area with a rectangular boundary and surveyed the apparent edges of the colony on foot to refine the location of the colony edges by eliminating peripheral areas that contained no potential nesting habitat. Areas excluded were permanent snow or ice fields, areas with standing water, and terrain lacking rock crevices.

The selected region was divided into 50 m $\times$ 50 m grid cells ($n = 201$). Selection of cell size was based on three competing considerations: (1) the need to visit each cell within the two-week survey period (argues for fewer cells), (2) the desire to have as many cells as possible to increase precision (argues for more cells), and (3) to increase the proportion of each cell surveyed (argues for small and therefore more cells; see below).

We randomly selected one point in each grid cell, which became the center point for a 16 m^2 (2.25 m radius) circular plot. These circular plots were surveyed in their entirety during periods of auklet activity (approximately 09:00 to 17:00) for signs of auklets. For the presence/absence survey, both indirect (droppings, feathers, birds standing on the surface, or vegetation trampling) and direct evidence of breeding (birds flying in and out of crevices, subsurface vocalization) were used to detect presence. Any of these signs resulted in that cell being designated as 'present.' Surface birds were recorded on an opportunistic basis, but no concerted effort was made to watch surface birds from a distance before visiting a survey plot.

We chose circular plots because they could be easily positioned from a single point. Randomized placement within the grid cell ensured independence of sample observations from any periodicity in auklet distribution. Plot size (16 m^2) was selected to be as large as feasible for thoroughly searching for auklet evidence and to allow us to visit every grid cell within the study's overall time constraints. The UTM coordinates for the grid cells and the randomly placed survey plot centers were generated using code written for the R Data Analysis Environment (R Development Core Team 2004) and uploaded to a handheld 12-channel WAAS-enabled GPS receiver (Garmin GPSmap 76s, Garmin International Inc., Olathe, Kansas). All survey points were found using the GPS

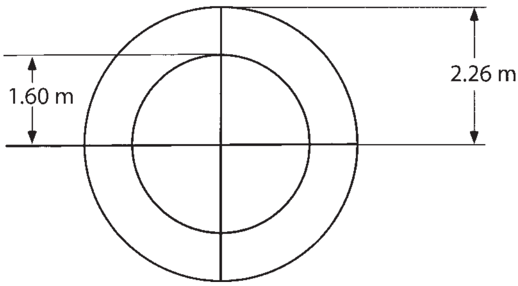

FIGURE 1. 16 m^2 auklet evidence density sample plot. Each circular plot was subdivided into eight sections of equal area. Plots were temporarily marked using two perpendicular ropes with stakes at the ends and center, and a knot tied in the rope showing the width of the inner circle. We rotated the rope around the center stake to measure whether items fell in or out of a given subplot.

receiver. Positional error, as indicated by the GPS receiver, was always <10 m, usually <5 m. To aid future relocation, locations of density plots were recorded repeatedly every 5 sec for 15 to 20 min and later averaged. Although true positional error is unknown, and may vary more across days than within days as measured, 95% of the measurements taken at each plot fell within 2 m of the mean. Stakes were not used to mark plots since previous experience at the colony indicated they do not remain in place over long periods. Plots were temporarily marked using two perpendicular ropes with stakes at the ends and center. Rotating the ropes around the center stake allowed quick assessment of whether items fell in or out of a given plot.

Density index. Every third grid cell plot in which auklets had been recorded as 'present' during the presence/absence survey was selected for a more intensive density survey. We estimated an index of auklet density throughout the colony by counting individual droppings and feathers (not just noting one or more occurrences as with the presence/absence survey). Within each 16 m^2 plot, data were recorded for each of eight equal-area subplots (Fig. 1) for ease of counting and to test variability within plots. Density plots were sampled during periods of both auklet activity and inactivity. Density survey plots were temporarily marked in the same way as presence/absence plots, and to identify the 2 m^2 subplots, a knot was tied in the rope showing the width of the inner circle (Fig. 1). Rotating the ropes around the center stake allowed quick delineation of each subplot.

Vegetation observations were made in each survey plot for comparison with future surveys, though results are not presented here. Cover abundance of vascular plants, bryophytes, and lichens was estimated using the nine-point ordinal scale of Westoff and van der Maarel (1973). Species composition was estimated based on percent total cover to the nearest 10%, and underlying substrate was recorded (soil, sand, beach boulders, talus, or unknown).

Survey timing. Our survey was conducted from 4 to 21 June 2004 at the Ulakaia Ridge colony, St. George Island, Alaska (56°35′N, 169°32′W). Timing coincided with the mid- to late-incubation period for auklets, indicated by an absence of adults carrying food in their gular pouches. By this time, auklets had already spent over a month at the colony, allowing for sufficient aggregation of indirect evidence (e.g., droppings and feathers) at the colony surface. Auklet attendance is also the least variable during this phase (Piatt et al. 1990). We confined the survey to an 18-day period to minimize the effects of changes in evidence during the survey period (i.e., significant additional accumulation or loss of evidence due to weather). No major storms, which could have washed or blown away evidence, occurred during our survey.

Assessment of density index. Because we lacked a direct measure of abundance, auklet sign density surveys were performed in single plots in the center of each of 14 established 10 m × 10 m attendance plots and in a long-term adult survival study plot. Attendance plots were selected in 1985 to represent high, medium, and low density breeding habitat within the auklet colony. The resulting counts of indirect evidence from the density surveys were compared to surface counts from these 15 plots to assess correlation of the two indirect measures.

Replicated surface counts were conducted during periods of activity (about 09:00–17:00) in the 14 attendance plots on 12, 17, and 24 June and in the survival plot on 12 June only. On each day, auklets were counted in each plot every 15 minutes during the activity period. Only nonzero counts were used for analysis, i.e., exodus due to predators and periods of nonattendance were excluded. Logarithmic transformations were used to approximately normalize the data. Attendance counts were summarized as the 10% trimmed mean of log (count + 1) in each plot, i.e., the mean of log (count + 1) after removing the smallest 10% and largest 10% of the observations.

Although each attendance plot was ostensibly 100 m^2, actual area varied due to minor angle measurement errors and plots occurring on a somewhat varying slope. Actual plot areas were calculated from the three-dimensional positions of the corners surveyed with a survey-grade differential GPS receiver in 2003 (accuracy ± 5 cm). Surveyed areas (accounting for topographic variation) ranged from 81.4–111.4 m^2. Attendance counts were converted to attending birds per m^2.

STATISTICAL ANALYSES

Colony area was estimated by multiplying the number of grid cells in which auklets were recorded as 'present' by the two-dimensional area of each grid cell (2500 m^2). A single plot-level auklet evidence density index was derived from the feather and dropping counts by using the first major axis of a principal components analysis (PCA) of the log-transformed counts (of droppings and feathers) + 1. Other measures of auklet evidence used in the presence/absence survey (e.g., vegetation trampling, subsurface vocalizations) were excluded from the density index because they were difficult to quantify. Colony maps including the distribution of occupied and unoccupied grid cells and the relative densities in occupied grid cells were produced using ArcGIS 8.3 (ESRI, Redlands, California).

To compare our density indices with surface attendance counts, we calculated Pearson's correlations across the attendance and survival plots between log ([attendance counts + 1] per m^2) and each of the dominant indirect density indicators, log ([feather counts + 1] per m^2), log ([dropping counts + 1] per m^2), and their derived PCA index. A 95% confidence interval for each correlation coefficient was estimated by bootstrap resampling with 5000 replicates (Lunneborg 2000).

To optimize the allocation of survey effort in future presence/absence surveys, we investigated the variation in evidence among the 2 m^2 subplots from the density survey. Consistency of indirect counts was assessed by estimating the proportion of variation in log-transformed feather and dropping subplot counts among plots versus among subplots within a plot using ANOVA. The reduction in probability of detecting occupancy when using smaller survey plots was estimated by calculating the mean probability of detecting presence in known occupied plots based on the proportion of their subplots with auklet evidence. The average probability of detection given the area of k (1–8) subplots (2 m^2 each) is then

$$\hat{p}[k] = \frac{\sum_{i=1}^{i=n} (1 - (1 - p_i))^k}{n},$$

with n being the number of occupied plots. All statistical calculations were conducted using the R Data Analysis Environment (R Development Core Team 2004).

RESULTS

PRESENCE/ABSENCE SURVEY

Sixty-two plots showed evidence of auklet activity (Fig. 2), yielding an estimated occupied colony area of 155 000 m^2 (62 × grid cell area of 2500 m^2). Feathers and droppings were the most frequent indicators of bird presence (Table 1), with one or the other occurring in 95% of the 'present' plots. Only three plots considered 'present' had neither feathers nor droppings; subsurface vocalizations were detected in one, and birds were observed on the surface while the observer approached the other two plots. Vegetation trampling was recorded in 76% of the 'present' plots but was difficult to quantify; eliminating vegetation trampling as evidence did not change any subplot's 'presence' status. Regurgitations of prey were not detected because no chicks were present during the survey period.

DENSITY SURVEY

Feathers and droppings were generally easily recognizable as distinct units. Feathers tended to be breast or belly feathers, which remained intact. In very few cases did droppings overlap each other such that they could not be accurately counted. No rain occurred during the 18-day study period, which could have washed away droppings.

Among those plots assessed for density, the density index (first major axis of PCA of log

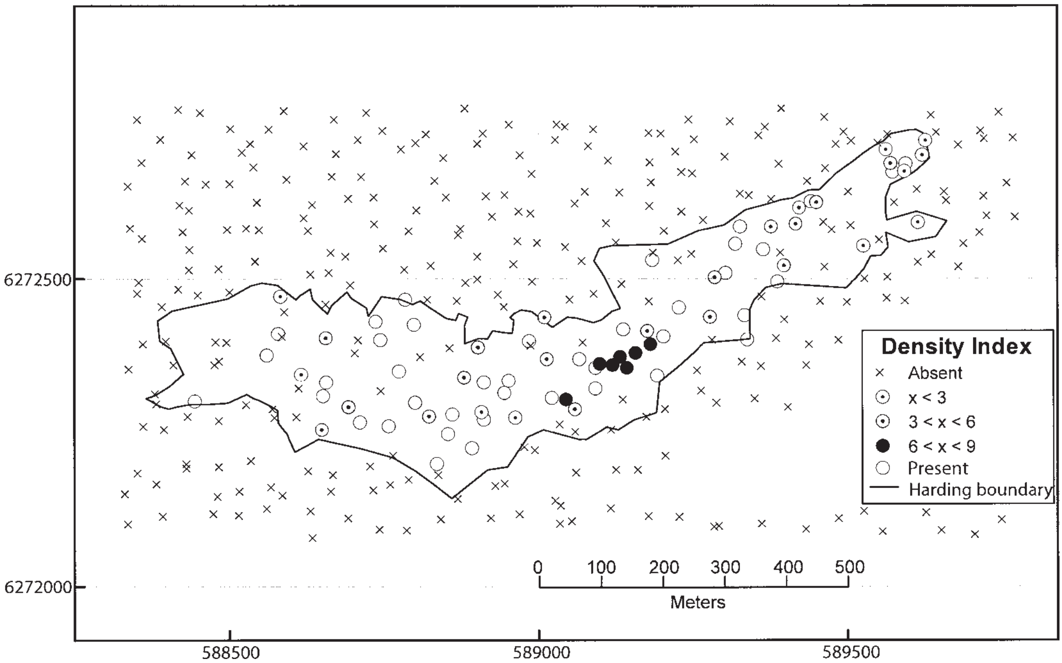

FIGURE 2. Map of the Ulakaia Least Auklet colony, St. George Island, Alaska showing points surveyed in 2004 (coordinates are UTM zone 2, datum WGS 84) and Harding's (2003) colony boundary. Auklet evidence density surveys were conducted on every third 'present' plot encountered in the field for the regular survey, as well as on the 15 permanent attendance and survival plots (not shown) for comparative purposes. Density values, x, are the first principal component of log + 1 transformed feather and dropping counts (Fig. 4d).

[count + 1] transformed feather and dropping counts) identified one small cluster of high auklet density and a larger area of low density, with zero density patches interspersed (Fig. 2). The auklet sign density index varied by two orders of magnitude throughout the colony. Log-transformed counts of feathers and droppings were strongly correlated with each other (Fig. 3a), and they and the derived density index were each strongly associated with log-transformed surface attendance counts (Fig. 3b–d).

Data from density plots provided a basis for retrospective evaluation of homogeneity of evidence used to determine occurrence of auklets, and to evaluate plot size. By definition, evidence was found in at least one subplot for the area to have been rated occupied, but we

TABLE 1. Frequency of various types of evidence used to infer presence of breeding Least Auklets at Ulakaia Ridge, St. George Island, Alaska, 2004. We visited 201 plots; 62 contained evidence of auklet presence. Percentage of total refers to the percentage of these 62 plots in which each type of evidence was recorded.

Evidence of nesting birds	Number of plots	Percentage of total
Droppings	52	84
Feathers	50	81
Vegetation trampling	47	76
Birds on surface	26	42
Subsurface vocalizations	26	42
Regurgitated prey	0	0
Nests observed	0	0
Total plots with birds present	62	

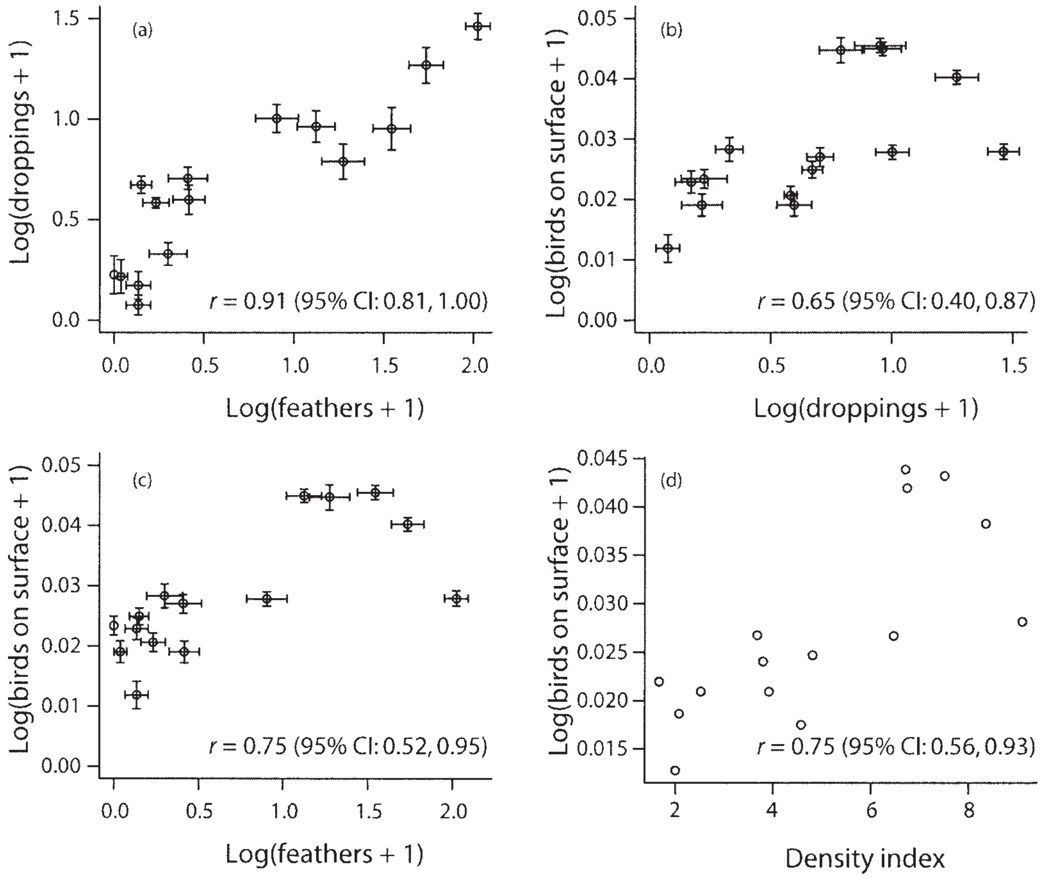

FIGURE 3. Plot-level associations between transformed indirect evidence counts (a), each indirect evidence count and mean attendance counts (b, c), and indirect density index and mean attendance counts (d) on the 15 permanent attendance and survival plots of the Ulakaia Least Auklet colony, St. George Island, Alaska. All points were transformed using natural log (x + 1). The attendance counts (birds on surface) are the 10% trimmed mean of nonzero counts from 12 to 24 June 2005. Indirect density evidence counts are from 16 m^2 density plots located at the center of each 10 m × 10 m attendance plot and consisted of eight 2 m^2 subplots (Fig. 1). Density error bars are standard errors from the subplots, i.e., counts on each of eight subplots were used as separate estimators of density on that particular plot; attendance error bars are standard errors from temporal variation in attendance counts.

found that evidence was present in all eight subplots in more than half (51%) of all 16 m^2 circular plots surveyed. Only 3% of the circular plots had evidence in only one of the 2 m^2 subplots. Overall, evidence of auklet presence was found in 81% of all subplots surveyed. Feather and dropping counts in subplots within a plot were relatively consistent, varying 30 and 16 times more, respectively, among plots than within. Reducing the survey plot size from 16 to 8 m^2 would have reduced the probability of detecting presence at a given plot by $<5\%$ (Fig. 4).

DISCUSSION

Colony extent and relative density are logistically feasible, statistically estimable, colony-wide monitoring metrics for auklets and other crevice-nesting seabirds. As such, they provide important, interpretable metrics for monitoring this group. With supplemental attendance counts to estimate relative proportions by species, these metrics could be applied to mixed-species colonies.

Our protocol requires only one survey to systematically cover the entire colony for both

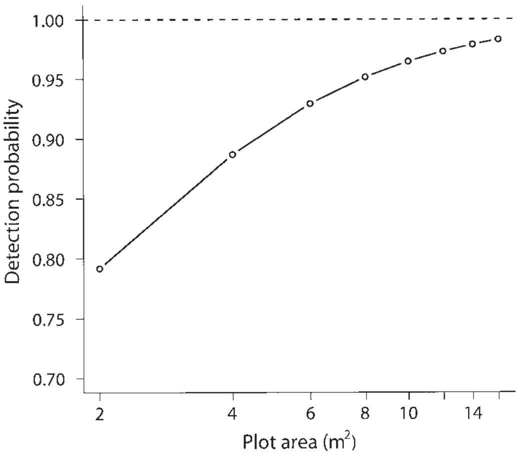

FIGURE 4. Estimated reduction in the probability of detecting auklets in an occupied grid cell as a function of survey plot size for the Ulakaia Least Auklet colony, St. George Island, Alaska.

extent and relative density, with both metrics overcoming many of the inherent problems of previous auklet abundance monitoring methods. The required specification of a spatial scale (grid cell) and survey plot size creates a standardization supporting comparisons among colonies. The unaligned (i.e., randomly selected) systematic sample of presence/absence provides a basis for estimating both long-term temporal change and its uncertainty, and geographic coordinates for colony locations allow for more powerful detection of changes in colony extent. The relative density mapping effort provides an important estimate of spatial variability in density across the colony. The auklet evidence density index provides a plot-specific metric strongly associated with the current attendance counts yet without some of their limitations. Because indirect evidence represents cumulative surface activity over several days or weeks, it may reduce some of the within- and among-day variation in colony counts that limits the power to detect population change.

Limitations of the proposed method include the need to complete the survey in two weeks or less to minimize changes in evidence during the survey, the potential for severe weather to remove accumulated feathers and droppings, and variation in persistence and detectability of evidence among habitats or observers. Application of this technique also requires prior identification of the survey area, to allow determination of grid cell and survey plot size.

THE ST. GEORGE TRIAL

Our estimate of the Ulakaia auklet colony area was 155 000 m^2, somewhat larger than an earlier average estimate of 95 000 m^2 (Hickey and Craighead 1977, mean of two surveys of 62 500 m^2 and 126 562 m^2). It is impossible to verify whether there was a true change in colony area because methods of the earlier survey were not sufficiently documented.

The colony's estimated shape was similar to that based on surface bird attendance (Harding 2003); all 'present' plots fell within Harding's boundary which encompassed an area of 239 461 m^2. However, the surveys differed not only in methods, but also in what they estimated. Harding's (2003) area estimate was based on mapping the colony periphery, thereby including uninhabited patches within the colony in the total colony area. The disadvantages of this method are that colony area is overestimated, the scale is not well-defined (making results difficult to reproduce), and relative density of breeding crevices is not evaluated. Our presence/absence survey accounted for uninhabited patches within the colony periphery, although it may potentially underestimate occupancy in low-density parts of colonies because only a small portion of each grid cell is surveyed. Our estimate of occupied area had a spatial resolution limited by the chosen grid-cell size. In enormous colonies where large grid cells would be necessary the two approaches could be combined, with perimeter mapping used to provide an upper boundary for colony area, and grid cell classification serving as a lower boundary. For this purpose a useful perimeter line can be quickly obtained on the first day of the survey when walking around the potential habitat to exclude unsuitable areas.

The auklet density survey assumes that the relative density index correlates with true densities of active breeding crevices. While densities of breeding birds remain unknown, our density index was strongly correlated with surface attendance counts. There has been much discussion as to whether surface counts can be reliably used as an index of abundance, because counts vary at multiple time scales due to factors such as weather, behavior, and food supply (Byrd et al. 1983, Piatt et al. 1990, Jones 1992). For example, one study at St. Paul Island, where most of the birds were marked so that numbers of breeding pairs were known, showed that the attendance count statistic in a single plot varied by a factor of 1.6 (0.2 orders of magnitude) across three years despite no appreciable differences in the number of breeding pairs (Jones 1992). In contrast, surface counts and our density index varied by two orders of magnitude across the Ulakaia colony, a much greater range than the interannual variability in the St. Paul Island plot. The relatively low variability in density among subplots within a plot confirms that the variability we detected across the colony reflects true variation in density and not measurement error. Thus, we are able to confidently identify areas of relatively high and low density.

Further, because variation within the colony is much greater than interannual variation observed due to behavior, it will be possible to attribute large-scale changes to true changes in density, although reduced power to detect a trend due to the variability of attendance data means that it might only be possible to detect rather coarse changes unless effort is increased. Year-to-year deviations from mean attendance (and therefore deposition of indirect evidence) due to behavior patterns are unlikely be biased. A recent study on crevice-nesting Horned Puffins (*Fratercula corniculata*) suggested that count variation associated with changes in behavior could be reduced sufficiently by protocol modifications to allow detection of changes in true abundance among years (Harding et al. 2005). Further work is needed to (a) examine seasonal and interannual variation in Least Auklet attendance counts, (b) determine the relative power to detect a trend in abundance among years using surface counts and indirect density indices, and (c) define the monitoring effort required to detect change of differing magnitudes among years.

SURVEY DESIGN CONSIDERATIONS

Number of grid cells. There are two main scale considerations when applying the proposed presence/absence survey: achieving a measurement precision as fine as possible, and maximizing the probability of detecting 'presence' in any plot. Both are optimized by dividing the survey region into the maximum feasible number (and therefore smallest size) of grid cells, n. The limiting factor is that all n cells must be surveyed within a relatively short period of time. This restriction stems from both logistic constraints imposed by travel to the research site and the need to minimize temporal change in evidence abundance across the region during the survey. The Ulakaia colony survey took little more than two weeks, minimizing temporal change in evidence abundance. Further studies should quantify the variability of auklet evidence counts within years, especially the effect of weather and the potential for accumulation throughout the season, allowing for future calibration of relative density across years. Until then, within-season error should be minimized by surveying at the same time of the breeding season each year and by keeping the duration of the survey to two weeks or less. Larger colonies will require larger crews.

Survey plot size. The effort required to survey the n cells is driven by the time spent locating and traveling between the n survey plots and the time spent surveying each plot, the former dictated by colony size, habitat, and n, the latter by survey plot size. Because only a small portion of each grid cell is surveyed, selecting survey plot size requires a trade-off between minimizing survey effort and minimizing the probability of misclassifying the cell's occupancy status. The survey can only misclassify by failing to detect presence in an occupied cell, thus estimated occupancy equals true occupancy $\times$ detection probability.

Many factors influence detection probability, including cell size, plot size, the spatial distribution of auklet nesting density, observer skill, spatial variation of habitats, and weather events. Once n is selected, survey plot size is the only other factor under the researcher's control. The relationship between survey plot size and detection probability depends on the spatial and density characteristics of each colony, limiting broad recommendations. However, the subplot information collected during the St. George survey allows for some refinement of a colony's survey design.

Surveying the Ulakaia colony with plots of 8 m^2 would have reduced the unknown detection probability by $<5\%$. Similar analyses of survey data from the Least Auklet colony on Hall Island in the northern Bering Sea, a relatively dense, more spatially uniform colony, showed that using plots of size 8 m^2 would have reduced detection probability by <1% (HMR, unpubl. data). No conclusions can be drawn on the effect of using larger survey plots.

Reducing survey plot size may allow additional time to increase *n* (number of grid cells), but not proportionally so because increasing *n* requires extra time for walking to and setting up plots. We recommend future surveys consider matching a reduction in survey plot size with an appropriate increase in the number of grid cells, rather than increasing the number of survey plots per grid cell, because this will result in improved measurement scale (increased precision) for a similar survey effort.

Variation in detection probability among habitats and observers. The Ulakaia auklet colony had vegetation and rock substrates relatively evenly distributed across it, minimizing variation in detection probability due to habitat (or more fundamentally, persistence of evidence). Deriving standardized relative density measures within a colony containing variable habitat, e.g., dense grass cover and beach boulders, remains an ongoing problem. Informal tests at Ulakaia suggested minimal variation among observers in detecting auklet evidence in subplots (counts were usually within 5%), and minimal measurement error (variation in repeated counts by the same observer), except for areas of very low breeding crevice density.

Considerations for time series monitoring. When possible, we recommend monitoring the same survey plots among years to eliminate variation due to randomly selecting new sets of survey plots. Although GPS error is typically greater than the sampling plot size, it can be reduced using differential GPS (Enge et al. 1988). Except for possible refinements after an initial survey, we also recommend keeping survey plot size constant across visits to guarantee consistency in relation to detection probability. If exact points cannot be relocated, we recommend keeping both the grid size and location constant among visits, with the possible addition of new cells at the survey region perimeter should the colony expand or shift beyond it. Keeping grid size constant eliminates changes in measurement scale across time and assures consistency of detection probability.

Documenting the expansion of a colony or occurrence of a new colony will provide important insights into population trends. Thus, it is just as important to document auklet absence at known locations as it is to document presence. The survey region should extend several grid cells beyond the expected colony perimeter. Limits of suitable auklet breeding habitat should be documented. The number of grid cells visited beyond the perimeter will depend on colony patchiness and boundary distinctiveness, but should be at least as great as the largest known gap among patches within the colony.

The current protocol is designed for colonies in large, contiguous areas of potential habitat. Modifications (e.g., strip transects of grid cells) will be required for other potential habitats such as beach boulder strips and cliffs.

Comparisons among colonies. Use of standard incremental grid cell sizes, such as 10, 50, and 100 m, would facilitate area comparisons across colonies by providing some control over differing measurement scales. This is, however, secondary to considerations of selecting grid cell sizes that maximize efficiency at a given colony.

Because auklets nest close to the surface, and surface area of a colony varies substantially with topography, comparisons of area among colonies should include a digital elevation model. Topography varies at every scale, but such a model of the Ulakaia colony using 20 m grid cells indicated that the estimate of surface area would increase by 1.3 to 1.4 times the two-dimensional area (HMR and MR, unpubl. data). Generating a digital elevation model requires recording an elevation with a GPS at each plot visited.

The auklet colony mapping method presented here is an important complement to ongoing attendance counts, providing a means for statistical estimation of changes in colony extent and relative density. Such information is critical for detecting the effects on auklet populations of climate change, plant succession, catastrophes such as oil spills and accidentally introduced nonindigenous predators (e.g., rats), and habitat changes due to natural causes such as landslides or lava flows. The proposed methods should be used to obtain baseline presence/absence and density information linked to geographic coordinates from all large auklet colonies, with a subset of colonies then selected for regular long-term monitoring.

ACKNOWLEDGMENTS

Valuable input to the protocol was provided by A. Gall and J. McDonough, and the protocol was tested at five colonies by B. Drummond, J. Dussureault, S. Kissler, J. Marais, A. Ritchie, and L. Sheffield in addition to the authors. G. Levandoski, K. Kauffman, and A. Sowls assisted with surface attendance counts at Ulakaia. J. Fox of NOAA kindly provided GPS data and ArcGIS layers from the 2003 survey by A. Harding and J. Adkins. We thank the people of St. George, the city of St. George, and the Tanaq Corporation for their hospitality and support during our stay, as well as the National Marine Fisheries Service for providing housing at the St. George Wash House. We are grateful to J. Piatt and an anonymous reviewer for suggestions that improved the manuscript, and to C. Zavalaga for the Spanish translation of the abstract. The survey sampling plot selection program is available by e-mail request from the second author (auklet@bigfoot.com).

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