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NOCTURNAL SPOTLIGHT SURVEYS FOR MONITORING SCRIPPS'S MURRELETS IN AT-SEA CONGREGATIONS AT ANACAPA ISLAND, CALIFORNIA

Darrell L. Whitworth¹ and Harry R. Carter^{2,3}

ABSTRACT.—Concealed nest sites, mostly inaccessible breeding habitats, and nocturnal colony visitation have long hindered studies of Scripps's Murrelets (*Synthliboramphus scrippsi*); but conspicuous and seasonally predictable at-sea congregations adjacent to nesting areas provide a valuable index for assessing murrelet colony size and population trends at all 12 breeding islands. We developed a boat-based nocturnal spotlight survey for counting murrelets in at-sea congregations at Anacapa Island, California. A high-intensity spotlight was used to count murrelets during standard surveys conducted on 2 parallel transects (1.9 km each) located 200 m ("inshore") and 500 m ("offshore") from shore. We conducted 130 standard surveys over 58 nights in 2001–2006. Difficulties estimating densities with strip transects and distance sampling led to use of raw counts as the best index for assessing population trends. Standard counts averaged 136 (SD 94) murrelets per survey (range 0–470). Strong correlations were noted among counts within nights, but consistent trends were not evident. We also noted a strong correlation between maximum counts on consecutive survey nights but much more variation in counts over the breeding season (annual CV range 27%–92%). Annual maximum counts occurred from 42 days before to 32 days after mean egg-laying dates. Round-island counts ranged from 29 to 564 murrelets during 12 surveys conducted along a 19.2-km transect circumnavigating Anacapa Island. Strong correlations between inshore and offshore standard counts and between standard and round-island counts indicated that major local shifts in distribution did not occur; instead, varying proportions of the murrelet population returned to the Anacapa Island congregation each night. Increases in standard counts from 2001 to 2006 and a positive correlation between standard counts and the annual number of clutches in monitored plots suggested an increase in the murrelet population after eradication of black rats (*Rattus rattus*) in 2002, but limited posteradication survey data were not sufficient to detect significant population trends. Intensive surveys (minimum of 10 nights each year) over at least 3 consecutive years per decade are recommended to track the progress of the Scripps's Murrelet population and to validate rates of population growth observed in small nest plots on Anacapa Island.

RESUMEN.—Durante mucho tiempo, los sitios de anidación ocultos, hábitats donde la reproducción es difícil y las visitas nocturnas a las colonias han obstaculizado los estudios sobre las aves de la especie *Synthliboramphus scrippsi*, pero las congregaciones conspicuas y estacionalmente predecibles en el mar, adyacentes a las áreas de anidación, constituyen un valioso parámetro para analizar el tamaño de la colonia y las tendencias de la población en 12 islas de reproducción. Realizamos conteos nocturnos desde embarcaciones de los individuos en congregaciones que se sitúan en el mar, en la Isla Anacapa, California. Utilizamos una luz de alta intensidad para hacer el muestreo durante los conteos "estándar" que realizamos en dos áreas transversales paralelas (1.9 km cada una) ubicadas a 200 m ("cerca de la costa") y 500 m ("en el agua") de la costa. Llevamos a cabo 130 conteos estándar durante 58 noches entre el año 2001 y el año 2006. Debido a que era difícil realizar estimaciones de las muestras a distancia y de la densidad del Método de transecto de banda, utilizamos el conteo en crudo como el mejor parámetro para analizar las tendencias de la población. Los conteos estándar promediaron 136 ± 94 aves por muestreo (rango = 0–470). Observamos una fuerte relación entre los conteos durante las noches, pero no detectamos tendencias significativas. Observamos una relación entre los conteos máximos durante las noches consecutivas que duró la investigación, sin embargo se registró una variación muy alta en los conteos correspondientes a la temporada de reproducción (Coeficiente de variación anual = 27%–92%). Los conteos máximos anuales se registraron desde 42 días antes hasta 32 días después de las fechas promedio en que las aves ponían los huevos. Los conteos en "toda la isla de reproducción" oscilaron entre 29 y 564 individuos durante 12 muestreos que se realizaron a lo largo de 19.2 km que circunnavega la Isla Anacapa. Las fuertes relaciones entre los conteos estándar cerca de la costa y en el agua, y entre los conteos estándar y en toda la isla de reproducción indicaron que no ocurrieron desplazamientos locales significativos en la distribución, sino que diferentes proporciones de la población aparentemente regresaban a la congregación de la Isla Anacapa cada noche. Los aumentos de los conteos estándar, entre los años 2001 y 2006, y la relación positiva entre los conteos estándar y la cantidad anual de puestas de huevos en terrenos monitoreados sugieren que se produjo un aumento en la población luego de la erradicación de ratas negras (*Rattus rattus*) en el año 2002; sin embargo, 6 años no fueron suficientes para detectar tendencias significativas en la población. Recomendamos realizar estudios intensivos (durante 10 noches cada año, como mínimo) durante por lo menos 3 años consecutivos por cada década para hacer el seguimiento del avance de la población de *Synthliboramphus scrippsi* y confirmar los índices de crecimiento poblacional que se observaron en pequeños terrenos con nidos en la Isla Anacapa.

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The secretive breeding behaviors and mostly inaccessible nesting habitats of Scripps's Murrelet (*Synthliboramphus scrippsi*) have long hindered knowledge of the species' ecology, status, and distribution. Scripps's Murrelets are small (167 g; Murray et al. 1983) marine birds (family Alcidae) that nest in concealed sites (e.g., rocky crevices or dense shrubs) on remote southern California and northwestern Baja California islands. Nocturnal visitation to nest sites and the short period of colony attendance (chicks leave nests just 2–3 nights after hatch and are raised at sea; Murray et al. 1983) further hamper nesting studies. Difficulties locating and assessing the size of murrelet breeding colonies have been exacerbated by the impacts of native and introduced mammalian predators, most notably island fox (*Urocyon littoralis*), feral cats (*Felis catus*), and rats (*Rattus* spp.), which restrict nesting at most islands to inaccessible coastal cliffs, sea caves, small islets, and offshore rocks (McChesney and Tershy 1998, Aguirre-Muñoz et al. 2008). By the mid-20th century, only remnant murrelet populations persisted in isolated and undocumented colonies on most islands (Jehl and Bond 1975, Carter et al. 1992, Drost and Lewis 1995, Burkett et al. 2003, Keitt 2005, Whitworth et al. 2013, 2014; H. Carter and D. Whitworth unpublished data). Concern for survival of Scripps's Murrelet (until recently classified as a subspecies of the former Xantus's Murrelet; Birt et al. 2012, Chesser et al. 2012) resulted in its listing as an endangered species in Mexico and as a threatened species in California; U.S. federal listing is still pending.

Considering this murrelet's small global population (7000–8000 breeding pairs; Karnovsky et al. 2005), limited breeding range (12 islands; Birt et al. 2012), and threatened status, as well as many ongoing conservation issues on islands and at sea (Carter et al. 2000), development of more effective population monitoring techniques for Scripps's Murrelet is a priority for long-term management and restoration. Through much of the 20th century, knowledge of the distribution, status, and trends of murrelet populations relied primarily on nesting studies at a few small islands; but information was lacking or speculative at other islands where murrelets nested mainly in inaccessible habitats. Scant information for most islands led to the misconception that 90% of Scripps's Murrelets in the Southern California

Bight nested at Santa Barbara Island and the Coronado Islands (Hunt et al. 1979, Carter et al. 1992, Drost and Lewis 1995), while populations on other islands were negligible or had been extirpated by introduced predators (Jehl and Bond 1975, Hunt et al. 1980). Clearly, an alternative to conventional nest monitoring was needed to better assess the overall status and distribution of Scripps's Murrelets.

One conspicuous feature of Scripps's Murrelet breeding and social behavior that facilitates colony detection and population monitoring is the at-sea congregations that form at night in nearshore waters adjacent to nesting areas (Gaston 1992, Whitworth et al. 1997, Gaston and Jones 1998, Hamilton et al. 2011, Whitworth and Carter 2012). Scripps's Murrelets are highly conspicuous and vocal in at-sea congregations, which form only during the prebreeding, egg-laying, incubation, and hatching periods (Murray et al. 1983, Whitworth et al. 1997). Murrelets do not appear to feed in at-sea congregations, and they only congregate off island coastlines with suitable nesting habitat (Hamilton et al. 2004, Whitworth and Carter 2012). At-sea congregation behavior was first described in 1917 (Howell 1917), but survey techniques using congregation activity to detect and roughly estimate the size of breeding colonies were not developed until 1994. In 1994–1999, at-sea vocal detection surveys at all islands in southern California and many islands in northwestern Baja California found Scripps's Murrelets more widespread and numerous than previously believed (Burkett et al. 2003, Keitt 2005, Whitworth et al. 2014; H. Carter unpublished data). However, difficulties interpreting the relationship between levels of vocal activity and the number of murrelets in at-sea congregations (or the number breeding on the adjacent shoreline) limited use of vocalization surveys for effective monitoring.

From 2001 to 2006, we developed a boat-based spotlight survey to count Scripps's Murrelets attending nocturnal at-sea congregations at Anacapa Island, California. Spotlight surveys were developed as part of a larger restoration and monitoring effort (2000–2010) to assess the response of the remnant murrelet population after the eradication of black rats (*Rattus rattus*) in 2002 (ATTC 2001, Howald et al. 2009, Whitworth et al. 2013). Nest monitoring in accessible plots in 2001–2010 demonstrated an overall positive response to the eradication

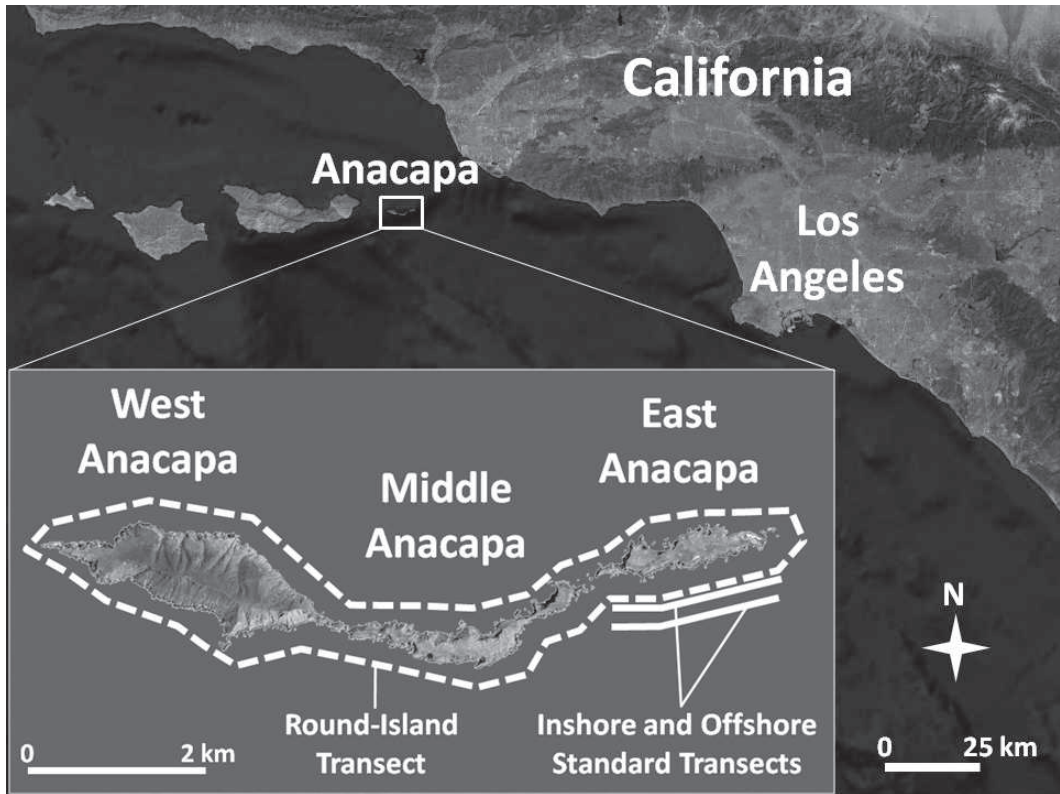


Fig. 1. The standard and round-island survey transects used during Scripps's Murrelet spotlight surveys at Anacapa Island ($34^{\circ}01'N$, $119^{\circ}22'W$), California, in 2001–2006.

of rats (Whitworth et al. 2005, 2013), but most of the recovering murrelet population apparently nested on inaccessible coastal cliffs that prevented a reasonable estimate of total population size with nest counts alone. The conspicuous and predictable nature of at-sea congregations facilitated use of spotlight survey counts as the best available index of overall population size and trends. Spotlight surveys have been frequently used with nocturnal terrestrial species (McCullough 1982, Smith and Nydeger 1985); but there are no published accounts of boat-based spotlight surveys being employed to assess seabird numbers or densities at sea, and no standardized data collection or analysis protocols have been established. In this paper, we (1) present the spotlight survey protocol developed and implemented at Anacapa Island; (2) examine spatial and temporal patterns in at-sea congregation attendance; (3) discuss the relationship between at-sea congregations and breeding on the adjacent island; and (4)

describe the difficulties of strip-transect (Tasker et al. 1984, Gould and Forsell 1989) and distance sampling (Buckland et al. 2001) density estimates that led to use of raw counts as the best available index of population size.

METHODS

Study Area

Spotlight surveys were conducted at Anacapa Island ($34^{\circ}01'N$, $119^{\circ}22'W$), California: one of 5 islands in the Channel Islands National Park. Anacapa Island lies about 20 km off the southern California coast and is the easternmost and smallest of the 4 northern Channel Islands. Anacapa Island comprises 3 islets (West, Middle, and East; Fig. 1) separated by narrow channels that are sometimes exposed at low tide. The island chain is approximately 8 km long and is surrounded by rocky cliffs and steep slopes punctuated with over 100 sea caves.

TABLE 1. Scripps's Murrelet nocturnal spotlight surveys at Anacapa Island in 2001–2006. Data include the range of survey dates in each year, the number of survey nights, the number of standard surveys in each nightly period (E = evening; N = night; M = morning), and the nightly maximum standard survey count (mean, standard deviation [SD], coefficient of variation [CV], and range).

Year	Nights (surveys)	Survey period			Nightly maximum count			
		E	N	M	Mean	SD	CV	Range
2001 (16 Apr–20 Jun)	12 (29)	10	12	7	121	83	69	1–269
2002 (27 Mar–22 May)	14 (33)	11	11	11	140	55	39	49–270
2003 (8 Apr–28 May)	13 (28)	13	11	4	196	52	27	107–262
2004 (13 Apr–1 Jun)	6 (12)	4	6	2	123	98	80	18–285
2005 (30 Mar–7 Jun)	10 (22)	10	10	2	251	146	58	55–470
2006 (6 Apr–5 May)	3 (6)	3	3	—	170	156	92	62–348

Spotlight Survey Protocol

Spotlight surveys were conducted during the Scripps's Murrelet breeding season (March–June) in 2001–2006 (Table 1). We conducted 2 types of spotlight surveys: (1) standard surveys, which consisted of 2 parallel transects (1.9 km each) located roughly 200 m (“inshore”) and 500 m (“offshore”) from shore in areas protected from prevailing winds and swells on the south side of East Anacapa Island; and (2) round-island surveys (19.2 km), which circumnavigated all 3 islets at distances between 200 m and 400 m from shore (Fig. 1). The inshore transect was located to safely sample the inner portion of congregation waters while avoiding shallow rocks and kelp near shore. The offshore transect was located to sample the outer portion of the main congregation without overlapping inshore transect coverage. We conducted standard surveys in 3 nightly periods (all times PST): “evening” (21:00–00:00), “night” (00:00–03:00), and “morning” (03:00–sunrise). Round-island surveys were conducted only during the evening or night periods.

Spotlight surveys were conducted in a 4-m Zodiac® inflatable craft powered by an outboard engine. The boat driver navigated the survey vessel at slow speeds ($\sim 8 \text{ km} \cdot \text{h}^{-1}$) along predetermined transects with the aid of a global positioning system (GPS) receiver. The observer seated at the bow (height about 1.5 m above the waterline) used a high-intensity spotlight powered by a 12-V deep-cycle marine battery to count all murrelets within visual range on each side of the boat. To scan both sides of the vessel while minimizing the number of birds missed or double-counted, the observer slowly passed the spotlight beam across a 90° arc starting at the port beam and proceeding toward the bow, then repeated the

movement starting from the starboard beam (Fig. 2). All data were called out to the data recorder who entered observations into a waterproof field notebook and took a GPS waypoint for each observation (2001–2003) or at the end of each 90° scan (2004–2006). Conditions (i.e., wind, Beaufort sea state, cloud cover, and moon phase) were recorded at the beginning of the survey and updated when conditions changed. Spotlight surveys were performed within a reasonable range of ocean conditions (wind $< 20 \text{ km} \cdot \text{h}^{-1}$, swells $< 0.5 \text{ m}$, sea state ≤ 2) to ensure comparability among counts.

We collected distance sampling (or line-transect) data (Buckland et al. 2001) during spotlight surveys in 2001–2003 to investigate the applicability of distance sampling analysis. Distance sampling data for each observation (i.e., murrelet or group) were recorded as follows: (1) radial distance (m) from the observer; (2) angle (°) off the bow; and (3) number of murrelets. To assist with angle estimation, we marked the pontoons of the inflatable craft at 15° intervals with the bow at 0°. We included all murrelets observed during surveys in raw counts, but distance sampling data could not be collected for flying birds or when densities were high. Given the need for a standardized data collection protocol that was practical over a wide range of murrelet densities, we discontinued distance sampling data collection after 2003 in favor of raw counts, which we considered the most efficient, comparable, and unbiased method of data presentation and analysis.

In 2004–2006, we simplified the data recording protocol to include (1) the total number of murrelets seen during each 90° scan; (2) the behavior of each bird; and (3) the GPS waypoint. Behaviors were classified as sitting on water, flying (i.e., in flight when detected), or flushed (i.e., sitting when detected but taking

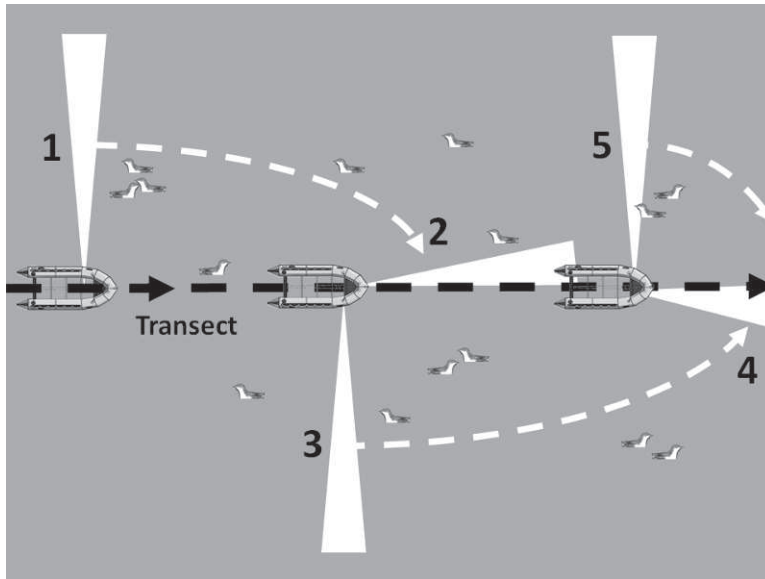


Fig. 2. Search pattern used to minimize the number of birds missed or double-counted during Scripps's Murrelet spotlight surveys at Anacapa Island, California. Numbers and white dashed arrows represent the sequence of movements used during spotlight scans: (1) beginning perpendicular to the port beam; (2) proceeding toward the bow; (3) shifting to the starboard beam; (4) proceeding again toward the bow; and (5) recommencing at the port beam.

flight soon after). All murrelets were included in counts regardless of behavior.

Data Analysis

DENSITY ESTIMATION.—We calculated 200-m strip-transect and distance sampling density estimates (murrelets \cdot km⁻²) for surveys in 2001–2003. The 200-m strip-transect width (100 m on each side of the vessel) corresponded with the maximum visual range of a life-sized murrelet model during field tests under excellent survey conditions. We used the program DISTANCE 4.1 (Thomas et al. 2003) for distance sampling analysis. The radial distance and angle for each observation were converted to perpendicular distances from the transect line, and these figures were then grouped into 5-m intervals to generate a histogram for each survey. DISTANCE 4.1 fit a detection function to the histogram to model the decreasing probability of detecting an object as its distance from the transect line increased (Buckland et al. 1993, 2001). We truncated observations beyond 50 m as recommended to allow the detection function to better fit the data (Buckland et al. 2001).

STATISTICAL TESTS.—We used paired-sample *t* tests to examine differences in spotlight counts

between consecutive evening–night and night–morning surveys within a night and between inshore and offshore transects for each standard survey. All means are presented with standard deviation. Pearson's correlation coefficient (*r*) was used to examine relationships between (1) 200-m strip-transect and distance sampling densities, (2) the proportion of murrelets lacking distance sampling data and the total count for each standard survey, (3) counts on consecutive evening–night and night–morning surveys within nights, (4) nightly coefficients of variation (CV) and means, (5) nightly maximum counts on consecutive nights, (6) inshore and offshore counts for each standard survey, and (7) standard and round-island counts on the same night.

Although data were limited to 6 years, we used time series regression to conduct a preliminary assessment of trends in standard spotlight counts for 2 parameters: the log-transformed (1) annual mean of the nightly maximum counts and (2) annual maximum counts (Nur et al. 1999). We used Pearson's correlation coefficient to examine the relationship between log-transformed counts of the number of nests in monitored plots and log-transformed values for (1) annual maximum

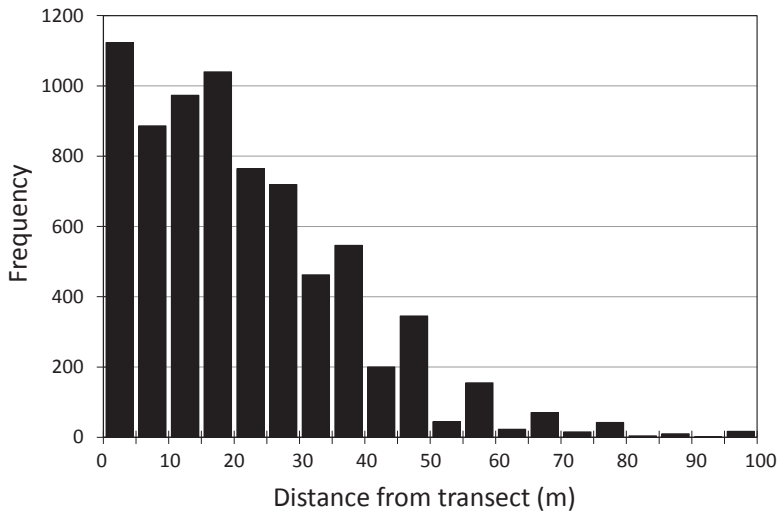


Fig. 3. Frequency of Scripps's Murrelets observed in relation to distance (grouped into 5-m bins) from the transect line during standard spotlight surveys at Anacapa Island, California, in 2001–2003.

and (2) annual mean of the nightly maximum counts.

RESULTS

Strip-Transect and Distance Sampling Density

In 2001–2003, strip-transect densities were estimated for 90 standard surveys conducted over 39 nights, whereas distance sampling densities were estimated for 88 surveys conducted over 38 nights. Data were insufficient to estimate distance sampling densities during 2 surveys on 20 June 2001 when only one bird was observed. Mean density was 164 murrelets \cdot km⁻² (SD 91, range 11–355) for 200-m strip transects and 390 murrelets \cdot km⁻² (SD 199, range 21–881) for distance sampling. Distance sampling and strip-transect density estimates were strongly correlated ($r = 0.85$; $P < 0.0001$); but distance sampling densities were invariably higher, with differences between the 2 estimates averaging 226 murrelets \cdot km⁻² (SD 130, range 7–544).

Distribution of the pooled perpendicular distance data indicated that detection rates were highest on the transect line (Fig. 3). However, increasing detections from 5 to 20 m demonstrated the lack of an evident “shoulder” necessary to reliably determine the value of the detection function. Examination of the raw radial distance and angle data indicated that we tended to heap observations at convenient

values. Observations at 0°, 30°, 45°, 60°, and 90° accounted for nearly half (49%) of the radial angle data; whereas observations at 10-m intervals accounted for 66% of the radial distance data, with heaping particularly obvious beyond 30 m from the observer. As a result, we noted few histograms (26%) displaying the “strong shoulder” (Fig. 4a) that promoted reliable modeling of the detection function (Thomas et al. 2003) but many (74%) skewed histograms (Fig. 4) with poor shoulders that provided unreliable density estimates.

Nearly half (46%) of the individual surveys and 18% of survey nights had observation samples lower than the minimum recommended for reliable density estimates (60 observations; Buckland et al. 2001). The proportion of murrelets lacking distance sampling data (but included in raw counts) on a particular survey (range 0%–47%) was negatively correlated ($r = -0.52$, $P < 0.0001$) with the spotlight count, indicating that we could not efficiently collect distance sampling data when murrelet densities were high.

Spatial and Temporal Trends in At-Sea Congregations

TRENDS IN CONGREGATION ATTENDANCE WITHIN AND BETWEEN NIGHTS.—We conducted 130 standard spotlight surveys over 58 nights in 2001–2006 (Table 1). The mean standard count was 136 murrelets (SD 94, range

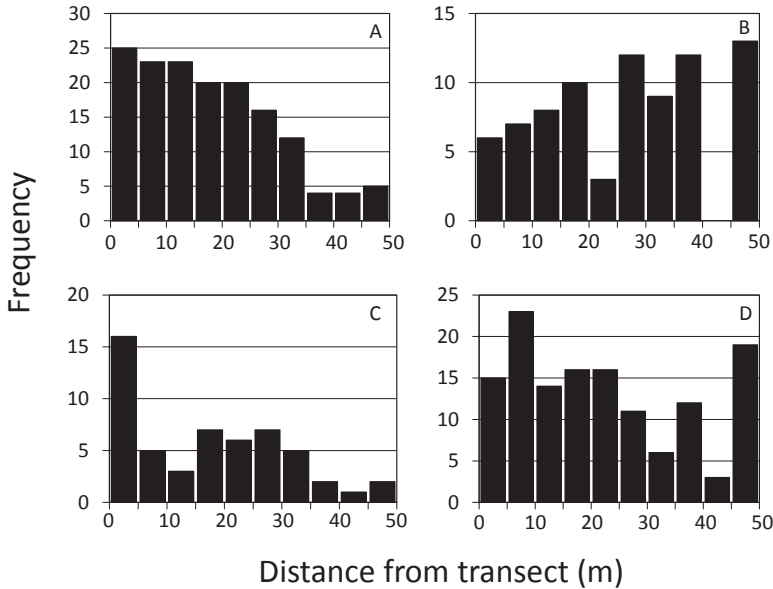


Fig. 4. Examples of distance sampling histograms (distances grouped into 5-m bins) used to model detection functions for Scripps's Murrelets at Anacapa Island, California, in 2001–2003. Only histogram A demonstrated characteristics that yielded reliable density estimates. Histograms B, C, and D demonstrated significant biases that would yield poor density estimates.

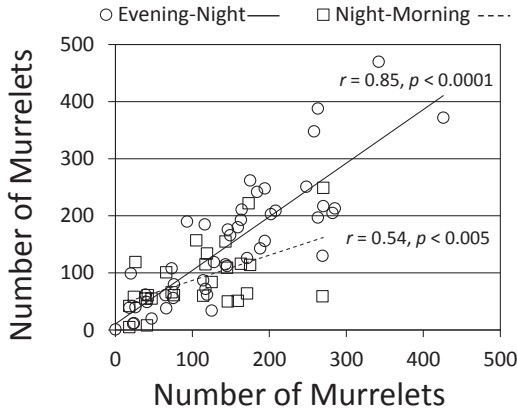


Fig. 5. Relationship between the number of Scripps's Murrelets observed on consecutive evening-night and night-morning periods during standard spotlight surveys at Anacapa Island, California, in 2001–2006.

0–470). Consistent temporal trends in spotlight counts were not evident within nights. Nightly maximum counts were not prevalent during any one survey period, although considerably fewer morning surveys were conducted. Maximum counts were recorded on 7 evening, 7 night, and 6 morning surveys on the 20 nights when 3 surveys were conducted. Maxi-

imum counts were also recorded on 22 evening, 19 night, and 11 morning surveys on the 52 nights when at least 2 surveys were conducted (Table 1). Counts did not differ between consecutive evening-night (paired $t_{45} = 0.16, P > 0.50$) or night-morning (paired $t_{25} = 1.54, P > 0.10$) surveys. But we noted strong correlations between consecutive evening-night ($r = 0.85, P < 0.0001$) and night-morning ($r = 0.54, P < 0.005$) surveys (Fig. 5). Occasional nights with high variation ($CV > 0.5$) were strongly associated ($r = -0.52, P < 0.0001$) with low nightly mean counts (Fig. 6). We also noted strong correlations ($r = 0.83, P < 0.0001$) between maximum counts on consecutive nights (Fig. 7). Because the maximum count best reflected the number of murrelets attending the at-sea congregation on a particular night, we used this as the preferred index for analyses of seasonal trends.

SEASONAL TRENDS IN CONGREGATION ATTENDANCE.—Survey counts over longer periods (i.e., several days or weeks) varied considerably within a breeding season, but no consistent seasonal patterns were evident (Fig. 8). Differences in nesting phenology (annual mean first egg-laying dates ranged from 10 April to 17 May; Fig. 8), survey effort (3–14 nights

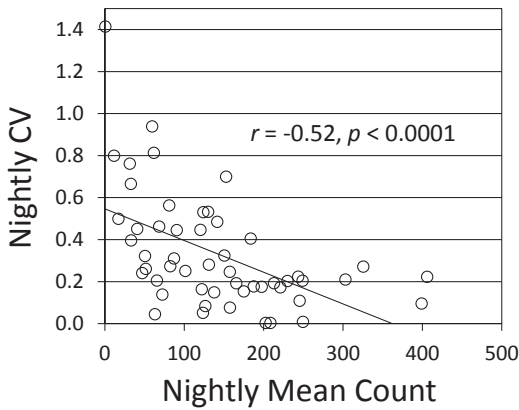


Fig. 6. Relationship between nightly variation (CV) and nightly mean counts during standard spotlight surveys at Anacapa Island, California, in 2001–2006.

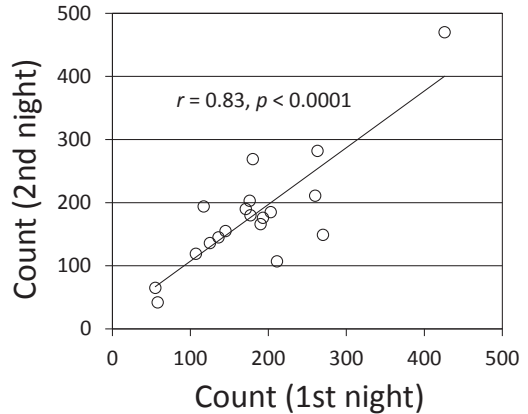


Fig. 7. Relationship between the numbers of Scripps's Murrelets observed during standard spotlight surveys conducted on consecutive nights at Anacapa Island, California, in 2001–2006.

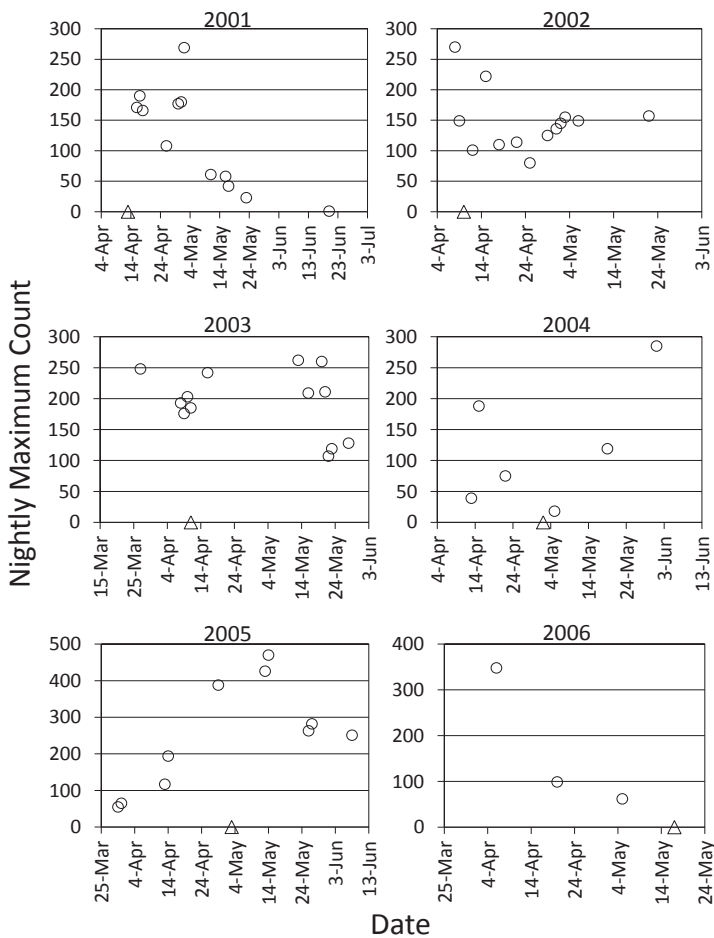


Fig. 8. Seasonal trends in nightly maximum counts during Scripps's Murrelet standard spotlight surveys at Anacapa Island, California, in 2001–2006. The annual mean egg-laying date is indicated by a triangle on the x-axis.

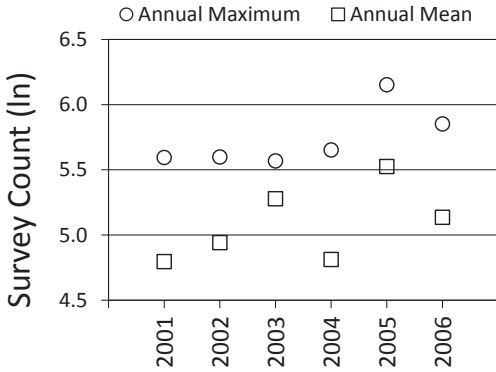


Fig. 9. Time series of the log-transformed annual maximum and annual mean nightly maximum counts during Scripps's Murrelet standard spotlight surveys at Anacapa Island, California, in 2001–2006.

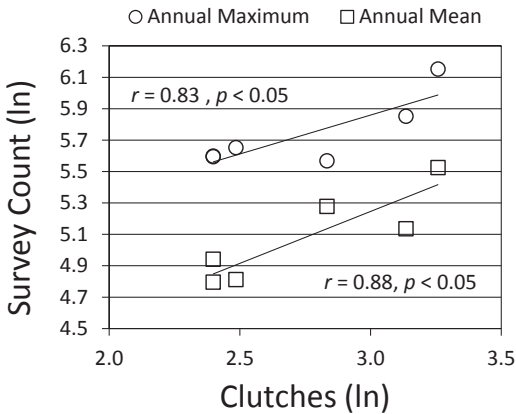


Fig. 10. Relationship between the number of Scripps's Murrelet clutches laid in monitored nest plots and the log-transformed annual maximum and annual mean nightly maximum counts during standard spotlight surveys at Anacapa Island, California, in 2001–2006.

each year; Table 1), and timing of surveys in relation to nesting likely contributed to the lack of consistent seasonal patterns. Annual peak counts occurred as early as 6 April (2006) and as late as 1 June (2004), but they did not appear to be related to a specific period of the breeding season. Peak counts occurred as many as 42 days before (2006) to 32 days after (2003) annual mean egg-laying dates (Fig. 8). Annual CVs ranged widely from 27% to 92% (Table 1). High CVs in some years were partly attributed to small survey samples (Table 1) or surveys conducted early or late in the breeding season when extremely low counts were recorded (Fig. 8).

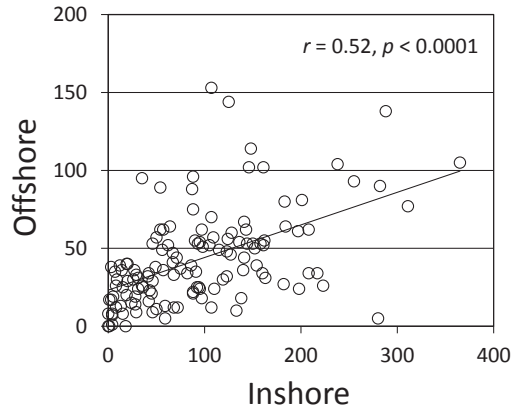


Fig. 11. Relationship between the number of Scripps's Murrelets counted on inshore and offshore transects for each standard spotlight survey at Anacapa Island, California, in 2001–2006.

INTERANNUAL TRENDS IN CONGREGATION ATTENDANCE.—General increases in the time series regressions for the log-transformed annual maximum ($r = 0.71$, $P > 0.05$) and annual mean nightly maximum ($r = 0.56$, $P > 0.05$) counts were not statistically significant (Fig. 9). Annual maximum counts provided a better fit to the time series regression, likely because annual mean nightly maximum counts were biased by extremely low early and late season counts. Both measures were likely biased by small survey samples in 2004 and especially 2006 that affected our ability to obtain representative spotlight counts in those years (Table 1). We noted significant correlations among the log-transformed number of murrelet clutches laid in monitored plots each year and the log-transformed annual maximum ($r = 0.83$, $P < 0.05$) and mean nightly maximum counts ($r = 0.88$, $P < 0.05$; Fig. 10), but data were too limited to reliably assess the relationship.

SPATIAL TRENDS IN AT-SEA CONGREGATION ATTENDANCE.—Counts on inshore and offshore transects for each standard survey were correlated ($r = 0.52$, $P < 0.0001$; Fig. 11), although counts were much higher (paired $t_{129} = 8.93$, $P < 0.0001$) inshore ($\bar{x} = 93$ birds, $SD = 75$) than offshore ($\bar{x} = 43$, $SD = 30$). Higher murrelet numbers were found offshore during just 31 of the 130 (24%) standard surveys, primarily on nights when overall standard counts were low.

We completed 12 round-island surveys, with counts (including the inshore transect of the

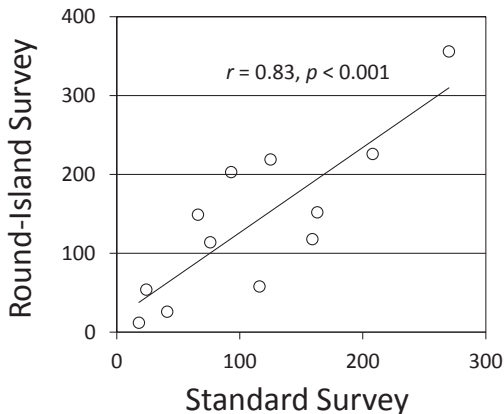


Fig. 12. Relationship between the number of Scripps's Murrelets counted on standard and round-island spotlight surveys conducted on the same night at Anacapa Island, California, in 2001–2006.

standard survey) ranging from 29 to 564 murrelets. Round-island counts (excluding murrelets on the inshore standard transect) were strongly correlated ($r = 0.83$, $P < 0.001$) with the corresponding standard survey counts (Fig. 12).

DISCUSSION

Scripps's Murrelet Breeding and At-Sea Congregations

Quantifying numbers of Scripps's Murrelets in nocturnal at-sea congregations with spotlight surveys is useful for 3 main purposes: (1) estimating population size; (2) monitoring changes in population size; and (3) examining breeding distribution around an island. The relationship between the number of murrelets attending at-sea congregations and the size of the breeding population at Anacapa Island was impossible to establish directly because we could not determine the number of nests on the largely inaccessible coastlines. Spotlight surveys in 2001–2006 indicated a much larger colony (about 200–400 pairs) than could be accounted for by the few nests found in accessible breeding habitats (Whitworth et al. 2005, 2013). However, correlations between standard spotlight counts and the number of murrelet clutches in monitored nest plots (Fig. 10) suggested a strong link between at-sea congregation attendance and the number of adults breeding each year, although more than 6 years of data are needed to reliably assess this relationship. Given the delayed sexual maturity in

murrelets (probably 2–3 years, as in the congeneric Ancient Murrelet [*S. antiquus*]; Gaston 1992), relatively large increases in spotlight counts were not expected until 2005 (3 years after rat eradication in 2002). We detected increases in the annual maximum and annual mean nightly maximum counts in 2005 (Table 1), as well as a large increase in the number of nests in monitored plots (Whitworth et al. 2013).

Given the strong natal philopatry and colony fidelity in alcids (Hudson 1985, Gaston and Jones 1998), the vast majority (if not all) Scripps's Murrelets observed in at-sea congregations at Anacapa Island were either adults breeding at the island or subadults attending the colony prior to breeding. Although small numbers of subadult Ancient Murrelets attended nonnatal colonies (Gaston 1992), banding studies conducted at Anacapa Island (about 450 birds banded over 8 years in 1996–2009) and the large colony at Santa Barbara Island (about 900 birds banded over 10 years in 1994–2010) failed to detect movements between islands (~65 km apart) by any individuals (Whitworth et al. 1997; D. Whitworth unpublished data).

Strip-Transect and Distance Sampling Density

Estimation of seabird density using strip transects (Tasker et al. 1984, Gould and Forsell 1989) or distance sampling (Buckland et al. 1993, 2001, Becker et al. 1997) is the most common method of analyzing abundance for diurnal shipboard surveys. Many studies have examined at-sea survey protocols and analytical methodology (e.g., optimal strip-transect width, accounting for bird movement and detectability [Spear et al. 1992, 2004, Hyrenbach et al. 2007, Ronconi and Burger 2009]), and specific techniques have been developed to better determine the position of birds in relation to the transect line or within a defined boundary (e.g., Heinemann 1981) to improve density estimates. However, nocturnal spotlight surveys have not been used previously to determine seabird numbers or densities. We found the particular conditions encountered during at-sea spotlight surveys to be quite different than those during conventional diurnal surveys, and these conditions were generally not amenable to density estimates using either strip transects or distance sampling.

STRIP TRANSECTS.—Our primary concern using strip transects with spotlight surveys

was the great difficulty we experienced determining the position of murrelets relative to a transect boundary. Estimating the distance of small, mostly dark-plumaged murrelets sitting on the dark ocean water while illuminated in the narrow spotlight beam was particularly challenging at night given the lack of visible reference points or a horizon for orientation, especially when large numbers of birds were present. In most cases, only the murrelets' conspicuous white breast was evident in the spotlight beam, such that the apparent size and perceived distance of the bird was largely dependent on its orientation in relation to the observer. Our experiences with the spotlight beam fixed on specific murrelets during night-lighting captures (Whitworth et al. 1997) demonstrated that the perceived distance from the observer was often deceptive and could change abruptly. We did not fix the beam on individuals during spotlight surveys to avoid causing birds to flush or move away from the vessel, which could have introduced serious biases to density estimates and counts. Simply counting murrelets during brief spotlight scans caused only minimal disturbance. Other complicating factors (e.g., the small fraction of the total survey area visible at any time and small numbers of flying or flushed birds) further compromised strip-transect density estimates.

We assumed a 200-m strip-transect width to calculate densities because field tests indicated that Scripps's Murrelets were visible up to about 100 m in the spotlight beam. However, distance sampling histograms suggested that 60 m was the maximum range of reliable detection for murrelets at night (i.e., observations more than 60 m from the transect line accounted for <1% of all observations; Fig. 3). Thus, 200-m strip-transect densities likely underestimated actual densities. Optimal strip-transect width for diurnal seabird surveys has received some attention (e.g., Hyrenbach et al. 2007), but we could not determine an appropriate transect width for the particular conditions encountered during spotlight surveys. Using narrower strip transects would probably not result in more accurate densities because perceived murrelet distance in the spotlight beam was deceptive regardless of distance from the vessel. Furthermore, biases could result if birds nearer the vessel, presumably more likely to make evasive movements,

moved beyond a narrower transect boundary before detection.

DISTANCE SAMPLING.—The prevalence of skewed perpendicular distance histograms (Fig. 4b–d) indicated considerable problems with distance sampling analyses that use spotlight survey data, probably due to violation of important assumptions during surveys. Accurate estimation of radial distances and angles is crucial (Buckland et al. 2001), but the obvious heaping of data at convenient values demonstrated the unavoidable difficulties we had estimating distances and angles at night which undoubtedly biased density estimates. Imprecise navigation on the transect line was an issue that affected the accuracy of radial angle data. Changes of bearing were often needed to correct for deviations from the transect line caused by periodic loss of GPS signal (particularly near the steep cliffs inshore) and currents or small swells that often altered the course of the slowly moving vessel. Because radial angles were measured with respect to markings on the vessel bow, changes in bearing greatly affected the accuracy of angle readings and consequently reduced the accuracy of perpendicular distances used for density estimates.

Evasive movements by murrelets in response to the survey vessel may have violated another principal assumption of distance sampling theory: detection of objects at their initial location (Buckland et al. 2001). Perpendicular distance histograms for the pooled data (Fig. 3) and several individual surveys (e.g., Fig. 4b) demonstrated increasing detections farther from the transect line, indicative of movements by murrelets from their initial position to avoid the survey vessel. Becker et al. (1997) reported little evasive movement by Marbled Murrelets (*Brachyramphus marmoratus*) during diurnal shipboard surveys in central California. However, Marbled Murrelets occurred in much lower densities in these surveys, and visible detection ranges during diurnal surveys were undoubtedly much greater than in nocturnal surveys, resulting in greater probability of detection before evasive movements occurred. The spotlight probably rendered the survey vessel more conspicuous and disturbing to Scripps's Murrelets, resulting in more evasive movements before detection.

Sample sizes for distance sampling analyses were also problematic. Many individual surveys and several survey nights had fewer than the

minimum 60 observations recommended for modeling a detection function (Buckland et al. 2001). On other nights, the observer was overwhelmed, particularly in 2003 when high numbers of birds prevented accurate and efficient data collection. Distance sampling is not recommended when objects are densely concentrated (Buckland et al. 1993, 2001). Expected increases in at-sea congregation densities as the murrelet population recovers after the eradication of rats (Whitworth et al. 2013) will likely make (or perhaps has already made) distance sampling analyses more difficult at Anacapa Island.

In 2003, after sufficient data had been collected to evaluate the advantages and disadvantages of the 3 data collection methods, we determined that standardized raw counts (1) provided the best possible comparisons for determining murrelet population trends—with the important requirement that all surveys be conducted within a narrow range of favorable conditions to ensure the observer's visual detection range is similar among surveys—and (2) greatly facilitated data collection compared to density estimates, which required difficult, time-consuming, and often unreliable assessments of murrelet position.

Spotlight Counts

POTENTIAL BIASES.—Bird movement has been identified as a significant cause of bias in at-sea survey data (Spear et al. 2004). Flying and flushed birds comprised only a small proportion (roughly 10%) of our total counts, but we considered these birds to be a potential source of bias (overestimation) causing double-counts of some individuals that may have landed in the survey area ahead of the vessel. However, 2 important considerations led to inclusion of all flying and flushed murrelets in spotlight counts: (1) we did not see any flying or flushed birds landing in the survey area ahead of the vessel to suggest that much double-counting occurred (although some murrelets may have landed far ahead beyond spotlight range) and (2) excluding all flying and flushed birds to avoid double-counting a few individuals posed a far greater risk of underestimation. Common methods to account for flying birds observed during diurnal surveys usually involve noting flight direction (Spear et al. 1992, 2004). However, we felt it was counterproductive to interrupt survey scans to determine the flight

paths of individual birds because it would be essentially impossible to recommence the scan at the point it was interrupted without double-counting or missing considerable numbers of individuals sitting on the water. Furthermore, experience during night-lighting captures (Whitworth et al. 1997) indicated that flight direction was greatly affected when the spotlight was fixed on murrelets, often causing disoriented birds to land on the water.

Attraction to the survey vessel did not appear to be an issue during spotlight surveys. Swimming murrelets did not approach the vessel and the few flying birds that approached did so because they were disoriented by the spotlight rather than attracted to the vessel. Though distance sampling histograms suggested that evasive movements in response to the vessel occurred (see above), it was highly unlikely that any of the slowly swimming birds were missed because they moved out of spotlight range. We very rarely observed diving or surfacing murrelets during spotlight surveys, although many birds dove to avoid capture when approached during night-lighting efforts.

VARIATION IN SPOTLIGHT COUNTS.—Spatial and temporal variability in Scripps's Murrelet at-sea congregations have been best studied on standard transects at Anacapa Island. Standard surveys offered several advantages compared to round-island surveys: (1) establishing standard transects in the lee of the island reduced effects from rough seas and prevailing winds, thereby maximizing the number of completed surveys; (2) calmer waters in the island lee also resulted in greater comparability among counts; (3) replicate standard surveys could be conducted each night; and (4) surveys were conducted near a secure anchorage that provided easy access to the standard survey area. The strong correlation between standard and round-island counts demonstrated that standard transects (~10% of the round-island survey area) sampled a representative portion of the total murrelet population. Thus, standard surveys are most appropriate for population monitoring. Round-island surveys are most appropriate for estimating population size and examining breeding distribution but also should be conducted to confirm that standard transects continue to represent the total population.

Reducing variation in survey data is crucial to reliable assessments of population trends.

We reduced spatial variability by sampling at different distances from shore on the inshore and offshore transects, but variation caused by local shifts in the distribution of murrelets in at-sea congregations around an island would be problematic for analysis of data from sample transects. However, strong correlations between inshore and offshore counts (Fig. 11) and between standard and round-island counts (Fig. 12) indicated that higher numbers in a particular area were usually associated with higher numbers elsewhere around the island. Thus, local shifts in distribution probably did not occur to any great extent; instead, the main source of variation between nights seemed to be varying proportions of the overall murrelet population that returned to the at-sea congregation each night and the other birds that remained at sea or spent a greater proportion of the night on the island. Considerable variation has been noted in the number of radio-marked Scripps's Murrelets that return to Anacapa Island each night (Hamilton et al. 2011), but the factors affecting attendance were not examined. Ancient Murrelets also exhibited considerable night to night variability in colony attendance, with ambient light and weather identified as factors affecting attendance; but also noted was an underlying periodicity (4 days), likely related to the length of the average incubation shift (2–4 days; Jones et al. 1990, Gaston 1992).

Although evening and morning peaks in vocal activity have been reported (Murray et al. 1983, Drost and Lewis 1995), we found no consistent patterns in congregation attendance within nights. The underlying causes of variation in spotlight counts within nights have not yet been examined, but the variation was probably a result of various environmental and behavioral factors (e.g., prey availability, foraging ranges, wind and ocean conditions, timing of family group departures, and predation risks related to ambient light or moon phase) that affected arrival and departure times at congregations. We disregarded temporal variability within nights by assuming that the nightly maximum count best reflected the number of murrelets attending the congregation on a given night. The lack of consistent trends within nights indicated that at least 2 surveys should be conducted to obtain a representative nightly maximum count.

The annual mean nightly maximum and annual maximum survey counts should be used as key parameters for measuring overall population trends with time series regressions. Adjustments to the annual mean nightly maximum counts will likely be necessary to account for seasonal variability in attendance (e.g., excluding early and late season counts when murrelet numbers are usually low); but assuming an adequate sample of survey nights, the annual maximum count does not require adjustments. Concurrence between parameters is expected, but different results could indicate potential biases affecting trend measurement. The lack of seasonal trends indicated that surveys should be conducted throughout the breeding season as often as financially and logistically feasible to ensure that representative counts are obtained. We have yet to assess the statistical power of existing data to detect trends in the Scripps's Murrelet population at Anacapa Island (e.g., Hatch 2003), but trends would likely not be evident after only 6 years, especially considering the limited samples in 2004 and 2006. At minimum, intensive spotlight surveys (minimum of 10 survey nights each year) over at least 3 consecutive years per decade are needed to track the progress of the Scripps's Murrelet population over time and validate rates of population growth observed in small nest plots on Anacapa Island (Whitworth et al. 2013).

Conclusion

The extensive spotlight surveys for Scripps's Murrelets at Anacapa Island in 2001–2006 have provided (1) valuable baseline data for measuring long-term responses of the murrelet population and for validating long-term trends from nest monitoring after the eradication of black rats; (2) useful information for designing and implementing exploratory and baseline surveys at other breeding islands in southern California and northwestern Baja California; and (3) valuable comparisons for better interpretation of data from colonies where such extensive survey effort has not been possible. In 2001–2013, we conducted baseline spotlight surveys at 7 breeding islands (Anacapa, Santa Barbara, San Miguel, San Clemente, Santa Catalina, Coronado, and Todos Santos islands), but thus far only preliminary round-island surveys have been

conducted at the other 5 breeding islands (Santa Cruz, San Jeronimo, San Martín, Cedros, and San Benito islands; D. Whitworth and H. Carter unpublished data). In addition to nest monitoring at key Scripps's Murrelet colonies, we urge implementation of spotlight monitoring programs to assess changes at all 12 breeding islands. An index relating numbers of murrelets in at-sea congregations and nests on the adjacent shoreline is being developed at Santa Barbara Island that will provide estimates of population size at all murrelet breeding islands using spotlight surveys (D. Whitworth and H. Carter unpublished data). Knowledge of population size and trends allows management agencies to undertake conservation actions to prevent colony extirpation and permit or encourage population recovery.

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