# LINE TRANSECT SAMPLING FOR MURRELETS: ACCOUNTING FOR INCOMPLETE DETECTION AND IDENTIFICATION

### STEVEN T. HOEKMAN<sup>1</sup>, BRENDAN J. MOYNAHAN<sup>2</sup>, MARK S. LINDBERG<sup>1</sup>, LEWIS C. SHARMAN<sup>3</sup> & WILLIAM F. JOHNSON<sup>2</sup>

<sup>1</sup>Institute of Arctic Biology, Department of Biology and Wildlife, University of Alaska Fairbanks, Fairbanks, Alaska, 99775, USA (sthoekman@alaska.edu) <sup>2</sup>Southeast Alaska Network, Inventory and Monitoring Program, National Park Service,

3100 National Park Road, Juneau, Alaska, 99801, USA <sup>3</sup>Glacier Bay National Park, Post Office Box 140, Gustavus, Alaska, 99826, USA

Received 13 April 2010, accepted 9 May 2011

# SUMMARY

HOEKMAN, S.T., MOYNAHAN, B.J., LINDBERG, M.S., SHARMAN, L.C. & JOHNSON, W.F. 2011. Line transect surveys for murrelets: accounting for incomplete detection and identification. *Marine Ornithology* 39: 35-44.

We assessed boat-based line transect sampling for monitoring population status and trend of the Kittlitz's Murrelet *Brachyramphus brevirostris* in Glacier Bay National Park and Preserve, Alaska. We used field experiments to compare efficiency of one versus two observers and to test the assumption that detection near the transect center line was 100%. Because coexisting Kittlitz's Murrelets and Marbled Murrelets *B. marmoratus* cannot always be distinguished on sight, we developed analytic methods to account for unidentified murrelets in density estimates. Relative to one observer, two observers had 56% higher encounter rates, a >20% higher probability of species identification, and better met the criteria for robust estimation of detection probability. More encounters also increase precision of estimated detection probability and group size. We estimated detection probability near the transect center line to be 0.94 (SE 0.03) and considered methods to relax the assumption of complete detection near the transect center line when estimating density. Relative to methods that exclude unidentified birds (53% of observations), analytic methods incorporating unidentified murrelets increased density estimates for both Kittlitz's and Marbled murrelets by >100% and reduced coefficients of variation by 9% and 15%, respectively. Failure to account for unidentified murrelets and for incomplete detection near the transect center line creates substantial and variable bias and error in density estimates, lessening the ability to assess population status and trend. We recommend the use of two observers, periodic calibration of detection near the transect center line and its incorporation into density estimates, and the use of skilled observers, periodic calibration of detection near the transect center line and its incorporation into density estimates, and the use of skilled observers, periodic calibration of detection near the transect center line and its incorporation into density estimates, and the use of skilled observers

Key words: line transect sampling, Kittlitz's Murrelet, *Brachyramphus brevirostris*, Marbled Murrelet, *Brachyramphus marmoratus*, detection probability, species identification, population monitoring

### **INTRODUCTION**

The Kittlitz's Murrelet Brachyramphus brevirostris is a rare seabird endemic to Alaska and northeastern Russia, with core populations in southern Alaska (Day et al. 1999). The species appears to be closely associated with glacially influenced habitats (Kuletz et al. 2003), and recent retreat of Alaskan glaciers combined with apparent population declines have led to its listing as a candidate species for protection under the US Endangered Species Act (US Fish and Wildlife Service 2010). Glacier Bay National Park and Preserve contains a significant population of Kittlitz's Murrelet (US Fish and Wildlife Service 2010), and the Southeast Alaska Network Vital Signs Monitoring Plan (Moynahan & Johnson 2008) has mandated monitoring of population status and trend. At sea, murrelets can be difficult to detect (Becker et al. 1997, Evans Mack et al. 2002, Ronconi & Burger 2009, Lukacs et al. 2010). We employed boatbased line transect surveys to estimate detection probability and density (Buckland et al. 2001). Distance sampling methods perform well when assumptions are met (Buckland et al. 2001, 2004, Efford & Dawson 2009), but assumptions may be difficult to meet and have rarely been tested for birds (e.g. Bachler & Liechti 2007, Diefenbach et al. 2007, Johnson 2008, Gale et al. 2009).

The critical assumption of line transect sampling is that all individuals near the transect center line (hereafter center line) are detected (Buckland et al. 2001). However, murrelets are small, cryptic, and highly mobile. In addition to swimming and flying, birds may escape detection by making prolonged dives (20-30 s) when foraging or disturbed (Evans Mack et al. 2002, Lukacs et al. 2010). Violation of the assumption of 100% detection near the center line introduces negative bias and error in density estimates (Buckland et al. 2001). An implicit assumption is that the study species can be consistently and correctly identified. However, morphologically similar Kittlitz's and Marbled murrelets coexist in Glacier Bay and can be difficult to distinguish (Day et al. 1999). Murrelets encountered on the water during surveys typically dive or flush when approached to within 50-150 m (Lukacs et al. 2010). Hence, large observation distances and short viewing times for birds near the center line are common, and at-sea surveys of these coexisting murrelets have reported large variation in identification rates (Agler et al. 1998, Drew et al. 2008, Kuletz et al. 2011). Excluding unidentified birds detected near the center line from density estimates is equivalent to incomplete detection. Bias associated with incomplete detection and identification might be alleviated or eliminated by increasing the number of observers. Boat-based surveys for murrelets have used either one or two observers, but differences in efficiency and ability to meet assumptions of methods have received scant attention (e.g. Evans Mack *et al.* 2002).

We conducted a field experiment to assess and improve methods for surveying Kittlitz's Murrelets in Glacier Bay. Specifically, we aimed to assess the critical assumption of complete detection near the center line and to assess efficiency and adherence to assumptions when using one versus two observers. We present analytic methods to relax the assumption of complete detection near the center line and incorporate unidentified murrelets into species-specific density estimates. Using pilot data, we demonstrate these methods and their effect on estimates of density and associated variance.

### STUDY AREA AND METHODS

### Study area

Recent recession of glaciers has exposed Glacier Bay, a narrow, ~100 km long fjord in southeastern Alaska (Fig. 1). The bay is characterized by numerous arms and small inlets, the upper reaches of which receive discharge of turbid water and ice from numerous glaciers. Complex bathymetry, produced by numerous deep basins and sills, leads to large variation in depth, tidal influence, water temperature, salinity, turbidity and productivity (Robards *et al.* 2003). Our study area encompassed 1092 km<sup>2</sup> of waters north of Icy Strait and excluded areas too small to allow safe passage, nonmotorized areas and critical habitat areas (Fig. 1).

### Sampling design

Convoluted topography presented challenges for representative sampling. Optimal design was also complicated by large spatial variation in densities in response to ephemeral concentrations of food, water depth and distance to shoreline (Zamon 2003, Arimitsu et al. 2007, Drew et al. 2008, Kirchhoff et al. 2010). Therefore, we sought a sampling design that provided reasonable coverage and spatial balance. We stratified based on density indices reported by Drew et al. (2008) and avoided placing transects parallel to density gradients. We defined a systematic series of parallel lines spaced 1 km apart, perpendicular to the local shoreline. Most transects ran shore-to-shore, but some transects running across the widest part of the bay were divided into two transects at mid-bay. We delineated a high-density stratum consisting of three areas where indices of Kittlitz's Murrelet density were about four times greater than elsewhere (Drew et al. 2008); the remaining area constituted a lowdensity stratum. Using Generalized Random Tesselation Stratified sampling (Stevens & Olsen 2004), we selected a random sample of 53 transects. Sampling probability was twice as high in the highdensity than in the low-density stratum.

### **Field methods**

We used distance sampling methods (Buckland *et al.* 2001) to conduct line transect surveys during 8–15 July 2009. We surveyed between 0800 and 1700 h with 1–3 observer(s) in the bow, a data recorder and a boat captain. Viewing height was ~2.5 m above the water in both the 9 m US National Park Service *M/V Capelin* (8–9, 13–15 July) and the 8 m US Geological Survey *M/V Boomer* (10–12 July). We used binoculars to aid in locating and identifying murrelets, which we classified to species when confidence in identification was high, but otherwise recorded as unidentified murrelets. We recorded

observations of groups (defined as murrelets of one class separated by <3 m between individuals) initially located on the water, and we recorded mixtures of classes as separate groups. At initial detection of groups, we recorded count, species class, estimated distance from observer(s) to the nearest 10 m (i.e. 0, 10, 20, 30 m, etc.), and estimated angular deviation from the center line. We continuously updated observations of Beaufort sea state, climatic conditions and visibility. When encountering high densities of murrelets, we sometimes reduced the standard survey speed of 10 km/h. When starting transects along the shore, we approached at low speed as close to shore as practical and recorded groups flushing from within 50 m of the center line before turning onto the transect. Few groups were encountered near shore, and our methods ensured groups near the center line were recorded. Data were recorded on laptop computers using dLOG3 software (Glenn Ford Consulting, Portland, Oregon). We did not sample when Beaufort sea state was >3 or when visibility was <100 m. This effort was part of a pilot study; observers were inexperienced at murrelet surveys but were experienced biologists and were trained in species identification and distance estimation over two days before and during surveys.

When we had enough personnel available, we conducted two field experiments. We assessed performance relative to number of observers by randomly assigning one or two primary observer(s), who cooperated in collecting survey data. To estimate detection of groups near the center line, we added an independent observer, who was positioned behind and out of sight of the primary observer(s). The independent observer used binoculars to detect groups ahead of the boat and near (<30 m) the center line before the primary observer(s) and monitored whether these focal groups were detected by the primary observer(s) during the survey. The independent observer did not record survey data or interact with primary observer(s), except to ask primary observer(s) to point out all groups detected to clarify whether they (primary observers) had detected focal groups.



**Fig. 1.** Location of Glacier Bay in southeastern Alaska, boundaries of low- and high-density sampling strata and location of line transects within the bay (black lines perpendicular to shore), July 2009.

### Statistical analyses

### Estimation of detection functions

We used the program DISTANCE (v6.0; Thomas et al. 2010) to estimate density and detection functions. We conducted standard exploratory analyses to determine appropriate right-truncation distances and bins for distance intervals (Buckland et al. 2001). For all analyses, we used Akaike's information criterion corrected for small sample sizes (AIC, Burnham & Anderson 2002, Arnold 2010) to select an appropriate key function and series expansion for models and to discriminate among competing models with different predictive variables. We considered the half-normal key function with either the Hermite polynomial or cosine series expansion terms and the hazard rate key function with either the simple polynomial or cosine series expansions. All series expansions included ≤2 adjustment terms. Unless stated otherwise, we fit detection functions to combined observations for all species classes. To assess potential differences in detection functions between Kittlitz's and Marbled murrelets, we used observations for these species to compare models with species separate or pooled. We assessed potential differences between density strata by comparing models with strata separate or pooled. Distance sampling assumes distances are accurate, groups are detected at initial locations and detection probability is 100% near the center line (Buckland et al. 2001). Robust estimation also requires that detection functions meet shape criteria by smoothly declining to an asymptote approaching zero distance and having a "shoulder," meaning the slope near distance zero should be about one.

### One versus two observers

We hypothesized two observers would detect more groups and groups at greater distances from the center line than a single observer. For transects randomly assigned one or two observers, we compared encounter rates and detection functions. We estimated encounter rate E within each density stratum d = 1 to 2 as  $\hat{E}_d = n/L$ , where n is groups detected and L is transect length (km). After Fewster *et al.* (2009), we estimated variance of  $\hat{E}_d$  as

$$\widehat{var}(\widehat{E}_d) = \frac{k}{L^2(k-1)} \sum_{i=1}^k l_i^2 \left(\frac{n_i}{l_i} - \frac{n}{L}\right)^2 \tag{1}$$

where  $n_1,...,n_k$  and  $l_1,...,l_k$  are number of groups and lengths, respectively, for *k* transects. We estimated *E* over the study area as the weighted mean of estimates from each stratum

$$\hat{E}_{.} = \frac{\sum_{d} A_{d} \cdot \hat{E}_{d}}{A}, \qquad (2)$$

where  $\Sigma_d$  is summation over strata,  $A_d$  is the area of stratum d, and  $A_{\perp}$  is area summed across strata. We estimated variance of  $\hat{E}$  as

$$\widehat{var}(\widehat{E}) = \frac{\sum_{d} A_{d}^{2} \cdot \widehat{var}(\widehat{E}_{d})}{A^{2}}.$$
(3)

We removed from analyses of encounter rates an extreme outlier (two observer, low-density transect with  $\hat{E} = 33$ ) that may have unrealistically inflated differences. To assess support for differences in detection functions, we constructed three models representing different hypotheses about effects of observers on detection functions: (1) a model with a pooled detection function (no difference), (2) a model with a covariate affecting the scale parameter of the key function (difference in scale but not shape), and (3) a model with separate detection functions for one versus two observers (difference in both shape and scale). We used AIC<sub>c</sub> to evaluate competing models. We used logistic regression analysis to assess factors influencing the probability of a group being classified to species. We hypothesized that lower task loads for two observers would increase identification, that increasing Beaufort sea state would decrease identification rates, and that identification would differ between observers. We modeled effects of number of observers and observer identities using indicator variables and sea state (as a continuous covariate). Because increasing distance hampers identification, we included perpendicular distance from the center line as a continuous covariate in all models. We used perpendicular rather than absolute distance to groups because observers normally monitored unidentified groups over time, and groups closest to the center line typically passed closest to observers. For this analysis, we included all survey transects, not just transects randomly assigned one versus two observers. We selected models using AIC<sub>c</sub> values. We first selected between linear and quadratic models of distance and then selected among all combinations of other predictors. Post-hoc examination of residuals suggested Beaufort sea state 3 greatly reduced probability of identification. To assess support for this observation, we added an indicator variable contrasting sea state 3 versus <3 to the top model in the candidate set.

#### Independent observer experiment

We estimated detection probability near the center line  $P_c$  using logistic regression analysis; focal groups monitored by the independent observer were considered detected if recorded by the primary observer(s) during the survey. We hypothesized detection rates would be lower with one observer and when Beaufort sea state was >1. We also hypothesized that detection would be lower during the first day of independent observer experiments (second day of surveys) than on later dates (fifth to seventh days), reflecting increasing experience of observers; if confirmed, we would prefer estimates from the latter period as likely more representative of observer performance in future surveys. We included these effects in models using indicator variables; climatic condition and visibility variables were invariant and hence excluded. From a set of models based on possible two-way combinations of explanatory variables, we selected a best approximating model using AIC<sub>c</sub> (Burnham & Anderson 2002). To compare abilities of one versus two observers to meet the assumption of complete detection near the center line, we added number of observers as a continuous covariate to the top model. Our methods assumed focal groups were representative of groups near the center line.

# *Estimating density while accounting for incomplete detection and identification*

Using distance sampling methods (Buckland *et al.* 2001), density *D* can be estimated as

$$\widehat{D} = \frac{\widehat{ES}}{2w\widehat{P}_a},\tag{4}$$

where *S* is group size, *w* is the right-truncation distance and  $\hat{P}_a$  is the detection probability for groups within the truncation distance estimated from the detection function. To estimate *S* for each species, we regressed log<sub>e</sub>(observed group size) on estimated detection probability. We used predicted values at the intercept of this regression if P < 0.05; otherwise, we used average group size. We estimated encounter rates separately for each species and stratum using methods described above. Using estimated detection probability near the center line  $P_c$  from the independent observer

experiment, we relaxed the assumption of complete detection near the center line:

$$\widehat{D} = \frac{\widehat{E}\widehat{S}}{2w\widehat{P}_a\widehat{P}_c}.$$
(5)

Introducing the  $P_c$  term adjusts the detection function to reflect groups missed near the center line; this adjustment can be implemented in the program DISTANCE using multipliers (Thomas *et al.* 2010).

We first estimated densities of Kittlitz's and Marbled murrelets using equation 5 and including only groups classified to species. For these analyses, we used pooled observations of both species to estimate a detection function. Above methods account for detection probability of identified groups but essentially treat unidentified groups as undetected, leading to violation of the assumption of complete detection near the center line and underestimation of density. To account for unidentified groups when estimating species-specific density, we assumed equivalent proportions of each species in the identified and unidentified samples (hereafter "assumption of equivalent proportions"). Because we expected proportions to vary by stratum, we estimated an adjusted encounter rate E' for each species m = 1 to 2 and stratum d = 1 to 2 as

$$\hat{E}'_{md} = \frac{\hat{E}_{md}\hat{E}_{ud}}{\sum_m \hat{E}_{md}} + \hat{E}_{md} , \qquad (6)$$

where  $\hat{E}_{ud}$  is the estimated encounter rate for unidentified groups in stratum *d* and  $\Sigma_m$  is summation over species. Thus, the encounter rate for each species was augmented by the proportion of unidentified groups likely belonging to that species. We estimated adjusted density *D'* for each species and stratum as

$$\widehat{D}'_{md} = \frac{\widehat{E}'_{md}\widehat{S}_m}{2w\widehat{P}_a\widehat{P}_c},\tag{7}$$

where  $\hat{P}_a$  was derived from a detection function fit to all observations. We applied the Delta method (Seber 1982) to estimate variance of  $\hat{D}$  for species *m* in stratum *d*:

$$\widehat{var}(\widehat{D}'_{md}) = (\widehat{D}'_{md})^2 \cdot \left\{ \frac{\widehat{var}(\widehat{E}'_{md})}{(\widehat{E}'_{md})^2} + \frac{\widehat{var}(\widehat{S}_m)}{\widehat{S}_m^2} + \frac{\widehat{var}(\widehat{P}_a)}{\widehat{P}_a^2} + \frac{\widehat{var}(\widehat{P}_c)}{\widehat{P}_c^2} \right\}.$$
(8)

To include appropriate covariance structure between encounter rates within each stratum, we calculated

$$\widehat{var}(\widehat{E}'_{md}) = \left(\frac{\partial \widehat{E}'_{md}}{\partial \widehat{E}_{1d}}, \frac{\partial \widehat{E}'_{md}}{\partial \widehat{E}_{2d}}, \frac{\partial \widehat{E}'_{md}}{\partial \widehat{E}_{ud}}\right) \cdot \widehat{\sum} \cdot \left(\frac{\partial \widehat{E}'_{md}}{\partial \widehat{E}_{1d}}, \frac{\partial \widehat{E}'_{md}}{\partial \widehat{E}_{2d}}, \frac{\partial \widehat{E}'_{md}}{\partial \widehat{E}_{ud}}\right)^T, \quad (9)$$

where  $\hat{\Sigma}$  is the estimated variance-covariance matrix of  $E_{1d}$ ,  $E_{2d}$ , and  $\hat{E}_{ud}$ . We weighted by stratum area  $A_d$  to estimate species-specific density across the study area:

$$\widehat{D}'_{m.} = \frac{\sum_{d} A_{d} \cdot \widehat{D}'_{md}}{A} \tag{10}$$

We then estimated variance for each species using the Delta method:

$$\widehat{var}(\widehat{D}'_m) = (\widehat{D}'_m)^2 \cdot \left\{ \frac{\widehat{var}(\widehat{E}'_m)}{(\widehat{E}'_m)^2} + \frac{\widehat{var}(\widehat{S}_m)}{\widehat{S}_m^2} + \frac{\widehat{var}(\widehat{P}_a)}{\widehat{P}_a^2} + \frac{\widehat{var}(\widehat{P}_c)}{\widehat{P}_c^2} \right\}. (11)$$

Because  $\hat{E}'_{m.}$  combined stratum-specific estimates, we weighted by stratum area to estimate its mean and variance for each species, as in equations 2 and 3. We estimated confidence intervals for density estimates following methods of Burnham *et al.* (1987) as modified by Buckland *et al.* (2001). Upper and lower confidence intervals were constructed as  $\hat{D}'/I$  and  $\hat{D}' \cdot I$ , where

$$I = \exp\left\{t_{df}(\alpha) \cdot \sqrt{\ln\left[1 + \frac{\widehat{var}(\widehat{D}')}{(\widehat{D}')^2}\right]}\right\}.$$
 (12)

To account for finite sample sizes, this method uses  $t_{df}(\alpha)$ , the critical value from Student's *t*-distribution for a  $100(1-2\alpha)\%$  confidence interval and degrees of freedom (*df*) for estimated density. Because

density for species s in stratum d combines parameter estimates with different df, we used the procedure of Satterthwaite (1946) to calculate approximate df as

$$df_{\hat{D}'_{md}} = \frac{\{\widehat{CV}(\hat{D}'_{md})\}^{*}}{\{\widehat{CV}(\hat{E}'_{md})\}^{*}/df + \{\widehat{CV}(\hat{S}_{m})\}^{*}/df + \{\widehat{CV}(\hat{P}_{a})\}^{*}/df + \{\widehat{CV}(\hat{P}_{c})\}^{*}/df},$$
 (13)

where each df is that associated with each component estimate. For estimates across strata, we computed df of  $\hat{E}'_{m.}$  as

$$df_{\hat{E}_{m.}'} = \frac{\left\{\sum_{d} \widehat{var}(\hat{E}_{md}')\right\}^{2}}{\sum_{d} \left\{\widehat{var}(\hat{E}_{md}')\right\}^{2}/df},$$
(14)

where df is that associated with each estimate of  $E'_{md}$ . We then calculated df for  $\widehat{D}'_{m}$  as

$$df_{\widehat{D}'_{m.}} = \frac{\{\widehat{CV}(\widehat{D}'_{m.})\}^{4}}{\{\widehat{CV}(\widehat{E}'_{m.})\}^{4}/df + \{\widehat{CV}(\widehat{S}_{m})\}^{4}/df + \{\widehat{CV}(\widehat{P}_{a})\}^{4}/df + \{\widehat{CV}(\widehat{P}_{c})\}^{4}/df}, \quad (15)$$

where each df is that associated with a component estimate.

### RESULTS

We surveyed 53 transects totaling 219 km on 8–15 July 2009. Three observers detected 1 064 groups. Group size averaged 2.63 (range 1–61). We classified 151 (14%) groups as Kittlitz's Murrelets, 348 (33%) groups as Marbled Murrelets and 565 (53%) groups as unidentified. Conditions were generally clear and calm during surveys. Beaufort sea state was <2 for 78% of observations, cloud cover was <50% for 80% of observations, and no precipitation was recorded.

Exploratory analyses of detection functions indicated detection probabilities were <0.15 beyond 220 m from the center line, so we truncated 40 observations beyond that distance. We grouped observations into bins of perpendicular distance from the center line (0–40 m for the first bin, 30 m ranges for subsequent bins) to improve adherence to recommended shape criteria (Buckland *et al.* 2001). Model selection results did not support differences in detection functions between species ( $\Delta AIC_c = 1.27$  for pooled versus separate detection functions) or density strata ( $\Delta AIC_c = 0.74$ for pooled versus separate detection functions), so we pooled species classes and strata for estimation of detection functions. The selected



**Fig. 2.** Estimated probability of detection of murrelets relative to perpendicular distance from the transect center line (curve) and scaled frequencies of groups detected in each distance category (bars), Glacier Bay, July 2009. Bar shading indicates relative composition of each species group within distance bins.

half-normal detection function (Fig. 2) showed adequate goodnessof-fit to observations, shown as scaled relative frequencies ("scaled frequencies") by distance bin. We estimated a detection probability ( $P_a$ ) of 0.65, SE 0.02, within 220 m and an effective strip width of 143.0, SE 4.0 m.

### One versus two observers experiment

We conducted analyses using 34 transects with a randomly assigned number of observers. Increases in estimated encounter rates with two observers were consistent across density strata (Fig. 3). Encounter rates (*E*) were 56% higher with two (3.74, SE 0.49) than with one (2.40, SE 0.57) observer. Comparison of scaled frequencies for one versus two observers showed large differences in frequency of observations by distance (Fig. 4). Observations for two observers declined gradually with increasing distance, resulting in a suitable distribution for estimation of a detection function. In contrast, observations for one observer dropped abruptly for distances >70 m, which violated shape criteria calling for a smoothly declining detection probability. We were unable to estimate a detection function for one observer with adequate goodness-of-fit.



**Fig. 3.** Estimated encounter rates (groups/km) and the associated SE for combined Kittlitz's and Marbled murrelets in low- and high-density strata during line transect surveys with one versus two observers, Glacier Bay, July 2009. Samples (n of transects) shown beneath estimates.

Selection results from our candidate set of models examining probability of identifying groups to species supported an effect of number of observers, but provided equivocal results for inclusion of Beaufort sea state as a continuous covariate (Table 1). Post hoc addition of an indicator variable contrasting Beaufort sea state 3 versus <3 received strong support. This result was consistent with our predictions, so we selected the enhanced model for inference. Probability of identification declined rapidly with increasing distance from the center line (Table 2) and decreased by almost half at Beaufort sea state 3 (Fig. 5). Average predicted identification rates across observed perpendicular distances, with sea state <3, were >20% higher for two observers (0.53, SE 0.02) than for one observer (0.42, SE 0.02).

#### Independent observer experiment

Independent observers included on 23 transects over four days (9, 13-15 July) located 90 focal groups. Trials were evenly split between one versus two primary observer(s), and Beaufort sea state was either 0 (79%) or 1 (21%). Focal groups were typically located far ahead of the boat (mean 279, SD 87 m), and 86% were estimated to be <30 m from the center line. Model selection results provided support for



**Fig. 4.** Scaled frequencies of groups detected versus perpendicular distance from the transect center line for one (n = 131) versus two (n = 498) observers, Glacier Bay, July 2009.

TABLE 1
Model selection results: estimation of probability of species identification for groups of murrelets
observed during line transect sampling, Glacier Bay, Alaska, July 2009 <sup>a</sup>

Model	K <sup>b</sup>	-2 log likelihood	$\Delta AIC_{c}^{c}$	AIC <sub>c</sub> weights <sup>d</sup>
Perpendicular distance <sup>e</sup> (quadratic) + no. of observers + Beaufort (indicator) <sup>f</sup>	5	1161.29	0.00	1.00
Perpendicular distance (quadratic) + no. of observers + Beaufort (continuous)	5	1176.52	15.23	<0.001
Perpendicular distance (quadratic) + no. of observers	4	1178.74	15.43	< 0.001

<sup>a</sup> Only models with  $\Delta AIC_c < 20$  presented.

<sup>c</sup> Difference in AIC<sub>c</sub> relative to the model with the lowest value.

<sup>d</sup> Weight of evidence as the best approximating model.

<sup>e</sup> Estimated perpendicular distance (m) of group from transect center line.

<sup>f</sup> Beaufort sea state included as an indicator variable for sea states 0–2 versus 3; variable added in post hoc analyses.

<sup>&</sup>lt;sup>b</sup> Number of estimated parameters.

differences in detection probability for the first relative to subsequent days of sampling (Table 3). Parameter estimates from the top model (intercept  $\beta = 2.76$ , SE 0.52, adjustment for first day  $\beta = -1.20$ , SE 0.75) predicted lower detection (0.83, SE 0.08) on 9 July than 13–15 July (0.94, SE 0.03), and we used the latter estimate of  $P_c$  in subsequent analyses. Adding number of observers to this model was not supported ( $\Delta AIC_c = 2.14$  relative to the top model).

# TABLE 2

Parameter estimates from the best approximating model predicting probability of species identification of Kittlitz's and Marbled murrelets during line transect sampling, Glacier Bay, Alaska, July 2009

• • • • • • • • • • • • • • • • • • • •	, = ,	
Parameter	β	SE
Intercept <sup>a</sup>	1.48	0.19
Perpendicular distance <sup>b</sup>	-0.0079	0.0045
(Perpendicular distance) <sup>2</sup>	-0.000065	0.000025
Adjustment: 1 Observer	-0.55	0.15
Adjustment: Beaufort =3	-1.29	0.31

<sup>a</sup> For surveys with two observers.

<sup>b</sup> Estimated perpendicular distance (m) from the center line.

# *Estimating density while accounting for incomplete detection and identification*

Regression of  $\log_{e}(\text{observed group size})$  on estimated detection probability was not significantly different than zero (P > 0.05) for



**Fig. 5.** Estimated probability of species identification for murrelets relative to distance and number of observers in line transect sampling, Glacier Bay, July 2009.

### Model selection results: estimation of probability of detection of murrelets near the transect center line, Glacier Bay, Alaska, July 2009

Model	K <sup>a</sup>	-2 log likelihood	$\Delta AIC_{c}^{b}$	AIC <sub>c</sub> weights <sup>c</sup>
First day separate	2	51.56	0.00	0.31
Intercept only	1	53.99	0.34	0.26
First day separate + Beaufort sea state	3	51.42	2.01	0.11
First day separate + no. of observers	3	51.56	2.14	0.11
Beaufort sea state	2	53.95	2.40	0.09
No. of observers	2	53.99	2.44	0.09
Beaufort sea state + no. of observers	3	53.95	4.53	0.03

<sup>a</sup> Number of estimated parameters.

<sup>b</sup> Difference in AIC<sub>c</sub> relative to the model with the lowest value.

<sup>c</sup> Weight of evidence as the best approximating model.

TABLE 4
Estimated densities D (individuals/km <sup>2</sup> ) of murrelets identified to species, and densities adjusted
for unidentified groups $D'$ from line transect surveys. Glacier Bay, Alaska, July 2009 <sup>a</sup>

for underlined groups D from the transect surveys, Glacier Day, Maska, July 2009					
Species	Density stratum <sup>b</sup>	D	D'	% Δ <b>D</b>	% ΔCV
Kittlitz's Murrelet	Low	4.1 (0.55)	9.9 (0.47)	140	-14
	High	8.6 (0.31)	17.4 (0.29)	101	-5
	All	5.4 (0.34)	12.0 (0.31)	122	-9
Marbled Murrelet	Low	11.5 (0.21)	26.8 (0.17)	133	-18
	High	12.2 (0.23)	26.0 (0.21)	114	-6
	All	11.7 (0.17)	26.5 (0.14)	127	-15

<sup>a</sup> Coefficients of variation (CV) in parentheses; change in adjusted relative to unadjusted estimates of density and CV expressed as percentages.

<sup>b</sup> Strata defined by expected densities of Kittlitz's Murrelets.

either species, so we used average group sizes of 2.40, SE 019, for Kittlitz's Murrelets and 2.18, SE 0.08, for Marbled Murrelets. Samples of observations for analyses using only identified groups (n = 462) were 45% smaller than for analyses using all groups (n = 1024), mainly because identified groups constituted only 47% of observations. Because identification rates dropped sharply at intermediate distances (Fig. 5), exclusion of unidentified groups resulted in steeper declines in detection (bars in Fig. 2), causing deterioration of the "shoulder" of the detection function and a righttruncation distance of 130 m rather than 220 m. Estimated densities were more than twice as high for Kittlitz's Murrelets in the highdensity than in the low-density stratum and for overall densities of Marbled than of Kittlitz's murrelets (Table 4). Accounting for incomplete detection near the center line increased estimates by 6.4%  $(1/\hat{P}_c)$  relative to estimates assuming complete detection. Methods accounting for incomplete identification increased estimated densities of Kittlitz's Murrelets by 122% and of Marbled Murrelets by 127% and also yielded 9% and 15% reductions, respectively, in estimated coefficients of variation (CV). For both species, variance in estimated encounter rates dominated total variance of density estimates (Table 5). Therefore, although increases in sample size increased precision of  $\hat{P}_a$  and  $\hat{S}$ , about 90% of the reduction in CV of density estimates resulted from increased precision of  $\hat{E}'$ , which was primarily due to inclusion of unidentified groups.

# DISCUSSION

We found violations of two critical assumptions of line transect sampling: both species identification and detection near the center line were less than 100%. These violations produced large negative bias in density estimates, but appropriate field and analytic methods allowed us to relax assumptions. Where Kittlitz's and Marbled murrelets coexist, both the magnitude and variation of species identification during surveys pose significant challenges for monitoring populations. For boat-based surveys in southeastern Alaska, identification rates have averaged 0.71 and varied substantially (SD 0.25, range 0.18-1.0) among studies and among years within studies (Agler et al. 1998, Lindell 2005, Kissling et al. 2007, Drew et al. 2008, Kirchhoff 2008, Kuletz et al. 2011, and this study). Few authors have reported distance of unidentified birds from the center line, but we found that unidentified groups near the center line were common (Fig. 2). Unidentified murrelets have typically been excluded from speciesspecific density estimates (e.g. Agler et al. 1998, Drew et al. 2008, Kirchhoff et al. 2010). This practice is suboptimal, because discarding unidentified birds detected near the center line is a *de facto* violation of the assumption of complete detection. These omissions represent a form of selection bias, where groups recorded near the center line are a negatively biased sample of the true number. Because distance sampling scales density estimates relative to densities at zero distance, densities are underestimated in proportion to the magnitude of incomplete detection.

# TABLE 5

Percent contribution to total estimated variance of density estimates of estimated encounter rates E', group size S, and probabilities of detection of groups within right-truncation distance  $P_a$  and near the center line  $P_c$  for Kittlitz's and Marbled murrelets in Glacier Bay, Alaska, July 2009

			, = 0	
Species	E'	S	$P_{a}$	$P_{c}$
Kittlitz's Murrelet	92	7	<1	1
Marbled Murrelet	85	6	4	5

Incomplete detection near the center line also produced negatively biased density estimates. Evans Mack *et al.* (2002) estimated detection of murrelets near the center line of ~0.9, with large variation among observers. Our slightly higher estimate (0.94) may reflect smaller wave heights in enclosed waters and slower survey speed, which may both increase detection (Evans Mack *et al.* 2002, Ronconi & Burger 2009, Lukacs *et al.* 2010). Additionally, our practice of reducing speed when encountering aggregations of murrelets likely promoted high identification and detection rates but assumed groups did not move substantially before detection (Buckland *et al.* 2001). Another potential source of bias in density estimates is failure of pooling robustness. Pooling assumes that moderate unmodeled heterogeneity in detection functions will not strongly bias density estimates, but that assumption is met only when detection near the center line is 100% (Buckland *et al.* 2004).

If unaccounted for, variation in identification and detection near the center line will introduce substantial, variable negative bias in population estimates that will degrade assessment of population status and complicate comparisons across space and time. For example, abundance estimates for Kittlitz's and Marbled murrelets in Glacier Bay that accounted for probability of detection and identification (Hoekman *et al.* 2011 and this study) exceeded prior estimates (Drew *et al.* 2008) that did not. The extent to which discrepancies reflect differences in methods rather than population change remains unclear and unresolvable (Hoekman *et al.* 2011). Biased estimates may be useful for monitoring trend (Johnson 2008), but large variation in bias amplifies temporal variation in abundance estimates and diminishes power to detect trends (Urquhart *et al.* 1998, Larsen *et al.* 2001).

In addition to reducing bias, incorporating unidentified murrelets in species-specific density estimates also slightly improved precision. Inclusion of unidentified groups and the resulting increase in righttruncation distance augmented our samples. Increased precision of density estimates stemmed primarily from improved estimates of encounter rates, which dominated total variance of density estimates. Because number of groups is in the numerator of the variance estimator (Eq. 1), improved precision resulted from "smoothing out" variation in encounter rates derived from variation in identification rates rather than from increased samples of groups. With increasing sample size, expected gains in precision for estimates of group size and detection probability will depend on estimation methods, but it is reasonable to expect that CV  $\propto 1/\sqrt{n}$ . An ancillary benefit of including unidentified groups was an improved "shoulder" for our detection function, which promotes robust estimates. Without unidentified murrelets, identification rates and hence detections dropped steeply at intermediate distances. Increased encounters could also reduce bias by providing sufficient samples for effective modeling of variation in detection relative to environmental or observer covariates.

The assumption of equivalent proportions holds when identification is correct and equal across species. We considered this assumption more reasonable than alternatives involving asymmetric identification rates because of the two species' similarity in morphology, behavior and diagnostic features, and because of expected similar effects of environmental conditions on detection and identification. We found circumstantial evidence consistent with our assumption. We did not find strong evidence that detection functions, which reflected both detection and identification, differed between species. Equivalence between species provided a more parsimonious explanation than did counter-balancing differences in detection and identification. If identification accuracy degrades with observation distance, using only observations from shorter distances may provide a more reliable estimate of the proportion of each species. However, analyses of 2009 and 2010 survey data did not support variation in proportions of each species relative to distance from the center line (Hoekman, unpublished data). We found proportions of each species differed between density strata, and such spatial variation can alter how unidentified groups are applied to species-specific density estimates. When estimating density, this proportion should be estimated separately for each area requiring separate inference, unless evidence supports no difference between areas.

Bias in density estimates from a moderate violation of the assumption of equivalent proportions is likely small, especially when identification rates are high, because error in the allocation of unidentified birds will be small relative to total population size for each species. However, misidentification is potentially quite problematic, especially between species with disparate abundances (Kirchhoff 2011). Even when probability of misidentification is equal between species, an abundant species will be classified as a rare species more than vice versa. In our case, misidentification of the more abundant Marbled Murrelet would inflate the estimated abundance of Kittlitz's Murrelet, a problem that would both mask decline in Kittlitz's Murrelets and be exacerbated by it. Analytic methods can ameliorate costs associated with incomplete identification, but misidentification is more difficult to detect and correct. Because misidentification can incur greater costs than nonidentification, we caution against increasing identification rates at the expense of accuracy.

Kuletz *et al.* (2011) presented a general method using nonlinear regression to estimate species-specific abundance and trend while accounting for unidentified species. Their approach shared our assumptions of equivalent proportions and correct identification. Kuletz *et al.* (2011) applied their methods to strip transect surveys for Kittlitz's and Marbled murrelets, but application to line transect surveys would not be straightforward because population estimates for unidentified murrelets are necessary. We could not estimate density for unidentified murrelets: decreasing identification rates with increasing distance resulted in increased observations of unidentified groups, thus violating shape criteria of decreasing detection with distance.

Identification rates during our pilot surveys (47%) were lower than desired, in part because of large viewing distances and because of our requirement for high confidence to classify groups as identified. However, we achieved much higher identification rates (>75%) with the same observers during 2010 surveys (Hoekman et al. 2011), emphasizing the role of inexperience in the low identification rates in 2009. Although our analytic methods reduced the repercussions of incomplete identification, the ideal solution would be to achieve high and accurate identification rates through training and evaluation of observers. However, factors such as variable environmental conditions, differences in viewing platforms and turnover in personnel, in combination with inherent difficulty of identification, will conspire to maintain variability in identification rates and accuracy. We suggest that analytic methods to account for unidentified species offer a useful supplement to, not a replacement for, skilled observers. Bias and precision issues associated with incomplete identification are mitigated by incorporating appropriate analytic methods, while experienced observers are better equipped to balance risks of incomplete versus misidentification.

During surveys, undetected focal groups often exhibited strong evasive movement and furtive behavior, including rapid swimming away from the center line (on or under water), prolonged dives (20–30 s), and short intervals between dives (<2 s). Even if evading birds were detected, such rapid, directed movement can violate the assumption of detection at initial locations. However, we did not observe such evasive movement by most groups until they were well inside typical detection. As also found by Lukacs *et al.* (2010), we concluded that a small fraction of murrelets exhibited strong evasive behavior and were unlikely to be detected. We recommend accounting for incomplete detection near the center line and suggest periodically calibrating estimates in relation to important sources of variation such as observer and weather conditions.

Boat-based surveys for murrelets have utilized one (Gould & Forsell 1989, Ralph & Miller 1995) or two (Agler et al. 1998, Raphael et al. 2007, Drew et al. 2008) observers. Having two observers incurs extra costs but may increase encounter and identification rates; purported benefits have rarely been assessed. A primary concern is whether one observer is less likely to meet assumptions of line transect methods. We did not find that single observers had lower detection rates near the center line, although our modest sample limited ability to discern differences. In contrast to two observers, an abrupt drop in observations for one observer violated shape criteria for detection functions. That decline may have resulted from observers "guarding" the center line to avoid missing detections there. Our observation of increased encounter rates with two observers and the conclusion of Evans Mack et al. (2002) that two observers had higher and less variable encounter rates during line transect surveys for murrelets both support the use of two observers to increase precision of density estimates. Higher identification rates with two observers likely resulted from reduced task saturation, which may also reduce identification error. High identification rates also help satisfy the assumption of equivalent proportions. Like Evans Mack et al. (2002), we recommend use of two observers.

## ACKNOWLEDGEMENTS

We are indebted to our boat captain J. Smith. We thank M. J. Conroy, S. M. Gende, J. L. Laake and P. M. Lukacs for critiquing versions of this manuscript. H. Coletti, B. Eichenlaub, S. M. Gende, J. I. Hodges, M. D. Kirchhoff, M. L. Kissling, C. Smith and W. L. Thompson contributed advice, logistic support or both.

### REFERENCES

- AGLER, B.A., KENDALL, S.J. & IRONS, D.B. 1998. Abundance and distribution of Marbled and Kittlitz's murrelets in southcentral and southeast Alaska. *Condor* 100: 254-265.
- ARIMITSU, M.L., PIATT, J.F., ROMANO, M.D. & DOUGLAS, D.C. 2007. Distribution of forage fishes in relation to the oceanography of Glacier Bay National Park. In Piatt, J.F. & Gende, S.M. (Eds). Proceedings of the fourth Glacier Bay science symposium, October 26-28, 2004. Investigations Report 2007-5047. Reston, VA: US Geological Survey. pp. 102-106.
- ARNOLD, T.W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. *Journal of Wildlife Management* 74: 1175-1178.

- BACHLER, E. & LIECHTI, F. 2007. On the importance of g(0) for estimating bird population densities with standard distancesampling: implications from a telemetry study and a literature review. *Ibis* 149: 693-700.
- BECKER, B.H., BEISSINGER, S.R. & CARTER, H.R. 1997. At-sea density monitoring of Marbled Murrelets in central California: methodological considerations. *Condor* 99: 743-755.
- BUCKLAND, S.T., ANDERSON, D.R., BURNHAM, K.P., LAAKE, J.L., BORCHERS, D.L. & THOMAS, L.J. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford: Oxford University Press.
- BUCKLAND, S.T., ANDERSON, D.R., BURNHAM, K.P., LAAKE, J.L., BORCHERS, D.L. & THOMAS, L. 2004. Advanced distance sampling: estimating abundance of biological populations. Oxford: Oxford University Press.
- BURNHAM, K.P. & ANDERSON, D.R. 2002. Model selection and multi-model inference: a practical information-theoretic approach. New York: Springer-Verlag.
- BURNHAM, K.P., ANDERSON, D.R., WHITE, G.C., BROWNIE, C. & POLLOCK, K.H. 1987. Design and analysis methods for fish survival experiments based on release-recapture. Bethesda, MD: American Fisheries Society Monograph 5. pp. 212.
- DAY, R.H., KULETZ, K.J. & NIGRO, D.A. 1999. Kittlitz's Murrelet (*Brachyramphus brevirostris*). In Poole, A. (Ed). The birds of North America, No. 435. Philadelphia & Washington, DC: Academy of Natural Sciences & American Ornithologists' Union.
- DIEFENBACH, D.R., MARSHALL, M.R., MATTICE, J.A. & BRAUNING, D.W. 2007. Incorporating availability for detection in estimates of bird abundance. *Auk* 124: 96-106.
- DREW, G.S., SPECKMAN, S., PIATT, J.F., BURGOS, J.M. & BODKIN, J.L. 2008. Survey design considerations for monitoring marine predator populations in Glacier Bay, Alaska: results and post-hoc analyses of surveys conducted in 1999-2003 [unpublished report]. Reston, VA: US Geological Survey.
- EFFORD, M. & DAWSON, D. 2009. Effect of distance-related heterogeneity on population size estimates from point counts. *Auk* 126: 100-111.
- EVANS MACK, D., RAPHAEL, M.G. & LAAKE, J.L. 2002. Probability of detecting Marbled Murrelets at sea: effects of single versus paired observers. *Journal of Wildlife Management* 66: 865-873.
- FEWSTER, R.M., BUCKLAND, S.T., BURNHAM, K.P., BORCHERS, D.L., JUPP, P.E., LAAKE, J.L. & THOMAS, L.J. 2009. Estimating the encounter rate variance in distance sampling. *Biometrics* 65: 225-236.
- GALE, G.A., ROUND, P.D., PIERCE, A. J., NIMNUAN, S., PATTANAVIBOOL, A. & BROCKELMAN, W.Y. 2009. A field test of distance sampling methods for a tropical forest bird community. *Auk* 126: 439-448.
- GOULD, P.J. & FORSELL, D.J. 1989. Techniques for shipboard surveys of marine birds. Technical Report 25. Washington, DC: US Fish and Wildlife Service.
- HOEKMAN, S.T., MOYNAHAN, B.J. & LINDBERG, M.S. 2011. Monitoring Kittlitz's Murrelets in Glacier Bay National Park: 2010 annual report. Natural Resource Technical Report NPS/ SEAN/NRTR—2011/441. Fort Collins, CO: National Park Service.
- JOHNSON, D.H. 2008. In defense of indices: the case of bird surveys. *Journal of Wildlife Management* 72: 857-868.

- KIRCHHOFF, M.D. 2008. Methodological considerations for at-sea monitoring of *Brachyramphus* murrelets in Glacier Bay, Alaska [unpublished report]. Douglas, AK: Alaska Department of Fish and Game.
- KIRCHHOFF, M.D. 2011. A review of selected surveys of the Kittlitz's Murrelet *Brachyramphus brevirostris* in Alaska: lessons learned. *Marine Ornithology* 39: 77–83.
- KIRCHHOFF, M.D., SMITH, M. & WRIGHT, S. 2010. Abundance, population trend, and distribution of Marbled Murrelets and Kittlitz's Murrelets in Glacier Bay National Park [unpublished report]. Anchorage, AK: Audubon Alaska.
- KISSLING, M.L., REID, M., LUKACS, P.M., GENDE, S.M. & LEWIS, S.B. 2007. Understanding abundance patterns of a declining seabird: implications for monitoring. *Ecological Applications* 17: 2164-2174.
- KULETZ, K.J., NATIONS, C.S., MANLY, B., ALLYN, A., IRONS, D.B. & MCKNIGHT, A. 2011. Distribution, abundance and population trends in the Kittlitz's Murrelet *Brachyramphus brevirostris* in Prince William Sound, Alaska. *Marine Ornithology* 39: 97–109.
- KULETZ, K.J., STEPHENSEN, S.W., IRONS, D.B., LABUNSKI, E.A. & BRENNEMAN, K.M. 2003. Changes in distribution and abundance of Kittlitz's Murrelets *Brachyramphus brevirostris* relative to glacial recession in Prince William Sound, Alaska. *Marine Ornithology* 31: 133-140.
- LARSEN, D.P., KINCAID, T.M., JACOBS, S.E. & URQUHART, N.S. 2001. Designs for evaluating local and regional scale trends. *Bioscience* 51: 1069-1078.
- LINDELL, J.R. 2005. Results of at-sea *Brachyramphus* murrelet surveys in Icy Strait and other selected areas of Southeast Alaska, 1993-1999 [unpublished report]. Juneau, AK: US Fish and Wildlife Service.
- LUKACS, P.M., KISSLING, M.L., REID, M., GENDE, S.M. & LEWIS, S.B. 2010. Testing assumptions of distance sampling of a pelagic seabird. *Condor* 112: 455-459.
- MOYNAHAN, B.J. & JOHNSON, W.F. 2008. Vital sign monitoring plan: southeast Alaska network. Natural Resource Report NPS/ SEAN/NRR—2008/059. Fort Collins, CO: National Park Service.
- RALPH, C.J. & MILLER, S.L. 1995. Offshore population estimates of Marbled Murrelets in California. In Ralph, C.J., Hunt, G.L. Jr., Raphael, M.G. & Piatt, J.F. (Eds). Ecology and conservation of the Marbled Murrelet. General Technical Report PSW-GTR-152. Albany, CA: US Forest Service. pp. 353-360.
- RAPHAEL, M.G., BALDWIN, J., FALXA, G.A., HUFF, M.H., LANCE, M., MILLER, S.L., PEARSON, S.F., RALPH, C.J., STRONG, C. & THOMPSON, C. 2007. Regional population monitoring of the Marbled Murrelet: field and analytical methods. General Technical Report PNW-GTR-716. Portland, OR: US Forest Service.
- ROBARDS, M., DREW, G.S., PIATT, J.F., ANSON, J.M., ABOOKIRE, A., BODKIN, J.L., HOOGE, P. & SPECKMAN, S. 2003. Ecology of selected marine communities in Glacier Bay: zooplankton, forage fish, seabirds, and marine mammals [unpublished report]. Anchorage, AK: US Geological Survey.
- RONCONI, R.A. & BURGER, A.E. 2009. Estimating seabird densities from vessel transects: distance sampling and implications for strip transects. *Aquatic Biology* 4: 297-309.
- SATTERTHWAITE, F.E. 1946. An approximate distribution of estimates of variance components. *Biometrics Bulletin* 2: 110-114.

- SEBER, G.A.F. 1982. The estimation of animal abundance and related parameters. 2nd edition. New York: Macmillan.
- STEVENS, D.L. & OLSEN, A.R. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* 99: 262-278.
- THOMAS, L.T., BUCKLAND, S.T., REXSTAD, E.A., LAAKE, J.L., STRINDBERG, S., HEDLEY, S.L., BISHOP, J.R., MARQUES, T.A. & BURNHAM, K.P. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* 47: 5-14.
- URQUHART, N.S., PAULSEN, S.G. & LARSEN, D.P. 1998. Monitoring for policy-relevant regional trends over time. *Ecological Applications* 8: 246-257.
- US FISH AND WILDLIFE SERVICE. 2010. Status assessment and listing priority assignment form for Kittlitz's Murrelet. Anchorage, AK: US Fish and Wildlife Service.
- ZAMON, J.E. 2003. Mixed species aggregations feeding upon herring and sandlance schools in a nearshore archipelago depend on flooding tidal currents. *Marine Ecology Progress Series* 261: 243-255.