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RESEARCH ARTICLE

Testing factors influencing identification rates of similar species during abundance surveys

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ABSTRACT

Most abundance estimation methods assume that all sampled individuals are identified correctly. In practice, this assumption may be difficult to meet and can bias abundance estimates, especially when morphologically similar species overlap in range. Over the past 2 decades, Kittlitz's Murrelet (*Brachyramphus brevirostris*) populations appear to have declined across parts of their Alaskan range, where they co-occur with the Marbled Murrelet (*B. marmoratus*). Recently, the reliability of Kittlitz's Murrelet declines has been questioned due to variability and uncertainty in species identification between the 2 species. We conducted a field experiment to quantify misidentification and partial identification (identification to genus [*Brachyramphus*] level only) of Kittlitz's and Marbled murrelets during abundance surveys, and to evaluate the relative impacts of environmental and observational factors on misidentification and partial identification. We applied these results to previously collected survey data to measure the potential bias of abundance estimates resulting from varying identification rates. Overall, the misidentification rate during our field experiment was 0.036 ± 0.004 (SE), with observer experience best explaining the variation. Abundance estimates adjusted for misidentification reflected little bias. The overall partial identification rate was much higher than the misidentification rate (0.211 ± 0.007 SE). Partial identification rates increased in choppy sea states, with greater observation distances, and when murrelets exhibited diving behavior; rates decreased with increased observer experience and when murrelets exhibited flushing behavior. Because observer experience was an important driver of both misidentification and partial identification, we stress the importance of conducting rigorous observer training before and during surveys to increase confidence in species identification and precision in abundance estimates. The methods developed in this study could be modified for any at-sea survey scenario to measure identification rates and the factors influencing these rates. Results may reveal important relationships for adjusting survey protocols to increase confidence in species identification and thereby to increase the precision of abundance estimates.

Keywords: *Brachyramphus* murrelet, Kittlitz's Murrelet, misidentification, partial identification, at-sea surveys

Prueba de los factores que influyen en las tasas de identificación de especies similares durante censos de abundancia

RESUMEN

La mayoría de los métodos para estimar abundancia suponen que todos los individuos muestreados son identificados correctamente. En la práctica esta suposición puede ser difícil de alcanzar y puede sesgar los estimados de abundancia, especialmente cuando especies morfológicamente similares tienen distribuciones superpuestas. Durante las dos décadas pasadas, las poblaciones de *Brachyramphus brevirostris* parecieron declinar en parte de su distribución en Alaska, donde la especie coexiste con *B. marmoratus*. Recientemente, la confiabilidad en cuanto al declive de *B. brevirostris* se ha cuestionado debido a la variabilidad e incertidumbre en la identificación de ambas especies. Hicimos un experimento en campo para cuantificar la identificación errónea y parcial (a nivel de género, *Brachyramphus*) de *B. brevirostris* y *B. marmoratus* durante censos de abundancia, y evaluamos el impacto relativo de factores ambientales y observacionales en la identificación errónea y parcial. Aplicamos estos resultados en datos de censos previamente recolectados para medir el sesgo potencial en los estimados de abundancia que resultan de la variación en las tasas de identificación. En general, la tasa de identificación errónea durante el experimento de campo fue 0.036 ($EE = 0.004$) y la experiencia del observador fue la variable que mejor explicó la variación. Los estimados de abundancia ajustados por identificación errónea reflejaron poco sesgo. La tasa de identificación parcial fue mucho mayor que la de identificación errónea (0.21 , $EE = 0.01$). Las tasas de identificación parcial incrementaron con el mar revuelto, mayor distancia de observación y cuando las aves buceaban; las tasas disminuyeron con mayor experiencia del observador y cuando las aves se espantaban. Debido a que la experiencia del observador fue una causa importante de la identificación errónea

y parcial, resaltamos la importancia de entrenar rigurosamente a los observadores antes y durante los censos para incrementar la confianza en la identificación de especies y la precisión en los estimados de abundancia. Los métodos desarrollados en este estudio pueden ser modificados para cualquier escenario de censos marinos para medir las tasas de identificación y los factores que influyen en dichas tasas. Los resultados pueden revelar relaciones importantes para ajustar los protocolos de muestreo para incrementar la confianza en la identificación de especies, y de esta manera incrementar la precisión en los estimados de abundancia.

Palabras clave: *Brachyramphus*, *Brachyramphus brevirostris*, identificación errónea, identificación parcial, censos marinos

INTRODUCTION

Detecting changes in population size forms the foundation of most wildlife monitoring programs. A common assumption of most abundance estimation methods is that all observed individuals are identified correctly (e.g., Buckland et al. 2001). However, this assumption can be difficult to meet, especially when morphologically similar species are potentially present.

Misidentification of species is a pervasive, though often overlooked, issue for wildlife monitoring programs (Bart 1985, Simons et al. 2007, McClintock et al. 2010, Conn et al. 2013). For example, Hull et al. (2010) found that observers misidentified 23% of juvenile Cooper's Hawks (*Accipiter cooperii*) as juvenile Sharp-shinned Hawks (*A. striatus*) at a raptor migration watch site. Further, expert observers misidentified 5% of anuran calls under simplified field survey conditions (McClintock et al. 2010). If species identification errors are not properly accounted for, bias may be introduced into abundance and trend estimates (Simons et al. 2007, Conn et al. 2013), limiting the ability of managers to make informed decisions or implement effective conservation actions. Accounting for errors in identification is especially important for species that co-occur in unequal proportions but are equally likely to be misidentified. In this circumstance, misidentification will disproportionately affect the less abundant species by artificially inflating its abundance estimates (Kirchhoff 2011, Conn et al. 2013). Because conservationists usually are more interested in the less abundant species, misidentification-induced bias could have potentially large implications for our ability to manage small populations effectively.

One method that has been used to minimize potential misidentification across taxa (e.g., Petitgas et al. 2003, Parente et al. 2006, Conn et al. 2013) is to identify individuals to the lowest taxonomic unit for which positive identification is certain (hereafter, "partial identification") instead of to the species level (Buckland et al. 2001). However, this can result in a large proportion of partially identified individuals, lowering the precision of species abundance estimates, hindering clear interpretation of species-specific trends, and complicating comparisons of results across space and time. Although allowing for partial

identification of individuals during surveys reduces the risk of committing misidentification errors, misidentification still may not be eliminated completely. Therefore, quantification of both the misidentification and partial identification rate and the environmental and observational factors influencing each is critical for accurate interpretation of abundance and trend estimates, particularly for rare species.

We examined misidentification and partial identification rates for 2 similar seabird species during at-sea abundance surveys. Interpreting trends from boat-based at-sea abundance surveys can be challenging for a number of reasons. Due to the highly dynamic nature of the marine environment, which affects both the spatial distribution of marine organisms and observer conditions, abundance estimates calculated from these surveys often have large variance (e.g., Rachowicz et al. 2006). Further, changes in methods and objectives complicate the comparison of results across studies (e.g., Tasker et al. 1984, Day 2011). For example, early surveys tended to record all marine wildlife encountered and recorded observations in units of birds seen per hour (Tasker et al. 1984), whereas fixed-width strip surveys and line transect surveys are most commonly used now. Identification uncertainty during at-sea surveys contributes further uncertainty to these abundance estimates.

Specifically, we addressed species identification errors and the factors contributing to them during at-sea surveys of Kittlitz's (*Brachyramphus brevirostris*) and Marbled murrelets (*B. marmoratus*) along coastal Alaska, USA. Over the past 20 years, apparent population declines of Kittlitz's Murrelet have occurred throughout a few core areas of its Alaskan range (Kuletz et al. 2011a, 2011b, Piatt et al. 2011), although causes of the downward trend remain unclear. Recently, both the magnitude and reliability of these declines have been questioned due to potential issues related to species identification, sampling design, and analysis (Day 2011, Hodges and Kirchhoff 2012, Kirchhoff et al. 2014). The coastal Alaskan range of the Kittlitz's Murrelet overlaps with that of the Marbled Murrelet, a morphologically similar and more abundant congener. These species often are surveyed concurrently because of their spatial overlap and physical and behavioral similarities. Due to the extreme and dispersed nesting



FIGURE 1. Two Marbled Murrelets (on left) and 2 Kittlitz's Murrelets (on right) during calm survey conditions, Glacier Bay, Alaska, USA, July 2013. Photo credit: National Park Service.

strategies of both species (Nelson 1997, Day et al. 1999, Barbaree et al. 2014), boat-based surveys are the most efficient method for estimating population abundance and trend (Drew and Piatt 2008, Day 2011). However, the diagnostic characters of each species can be difficult to detect at great distances or under difficult light and sea conditions (Figure 1). Consequently, Kittlitz's and Marbled murrelets are potentially subject to both misidentification and partial identification during surveys.

In nearly all areas where these 2 species overlap, species composition is highly skewed, with Marbled Murrelets greatly outnumbering Kittlitz's Murrelets. Thus, misidentification-induced bias in abundance estimates would be expected to have a disproportionate effect on abundance estimates of Kittlitz's Murrelets, the rarer species. Further, varying proportions of murrelets are identified only to the genus level during surveys (range = 0.00–0.89; Kuletz et al. 2011b, Kissling et al. 2011, summarized in Day 2011), adding additional uncertainty to abundance and trend estimates. During analysis, this proportion of partially identified murrelets is either withheld from species-specific abundance and density estimates, which could bias estimates low, or allocated to the species level based on species proportions for a given spatial scale (Day 2011). The scale at which this allocation occurs varies among study areas (study area: e.g., Hoekman et al. 2014; stratum: e.g., Kendall and Agler 1998; or transect: e.g., Arimitsu et al. 2010). Because Kittlitz's and Marbled murrelets are distributed differently within a study area depending on habitat characteristics (Day et al. 1999, 2003), large-scale (study area) species proportions could be very different from fine-scale (transect) species proportions. Therefore, this variation in methods further complicates the comparison of results across studies.

We conducted a field experiment to quantify misidentification and partial identification rates of *Brachyramphus* murrelets during abundance surveys carried out at sea and to identify the environmental and observational factors influencing these rates. We predicted that misidentification and partial identification would increase with greater observation distances, lower observer experience levels, rougher seas, sunny and rainy weather conditions, larger murrelet group sizes, evasive diving behavior, and in mixed-species groups. We then applied the results of the field experiment to previously collected at-sea survey data to measure potential bias in abundance estimates resulting from varying identification rates, and to evaluate different methods of allocating partially identified *Brachyramphus* murrelets to the species level. The overall goal of the latter objective was to determine the appropriate spatial scale at which the allocation should occur to facilitate the interpretation and comparability of abundance estimates.

METHODS

Field Methods

We conducted our field experiment in Glacier Bay National Park and Preserve, Alaska (58.5°N, 137.0°W; Figure 2), July 13–18, 2013, when most abundance surveys for this species in Alaska are conducted (Day 2011). Glacier Bay is a deep, narrow fjord located in southeastern Alaska, with ~3,560 km² of marine surface area. As is the case in most areas within the Kittlitz's Murrelet's range, Marbled Murrelets greatly outnumber Kittlitz's Murrelets in Glacier Bay, with the most recent population estimates being 10,422 (\pm 1,522 SE) Kittlitz's and 41,474 (\pm 3,988 SE) Marbled murrelets (Sergeant et al. 2014). Within the bay, we confined the field experiment to the Sitakaday Narrows and the Beardslee Islands, where both species of murrelets occurred in sufficient numbers to conduct the experiment efficiently (Sergeant et al. 2014).

The field experiment followed the at-sea, distance sampling survey protocol outlined in Kissling et al. (2007), in which observers recorded the perpendicular distance (m) of murrelet groups from the transect line, murrelet group size, and environmental variables. During the experiment, we made minor adjustments to the protocol to maximize the efficiency of data collection. Prior to beginning the field experiment, we trained 6 observers, each with a different level of existing experience (range: 1–5 yr), how to identify murrelets based on distinguishing characteristics. We encouraged all observers to identify murrelets to the species level, while also providing them the option of recording murrelets to the genus level only (partial identification). Four people participated in the field experiment at the same time: 2 observers, 1 photographer, and the boat captain. We

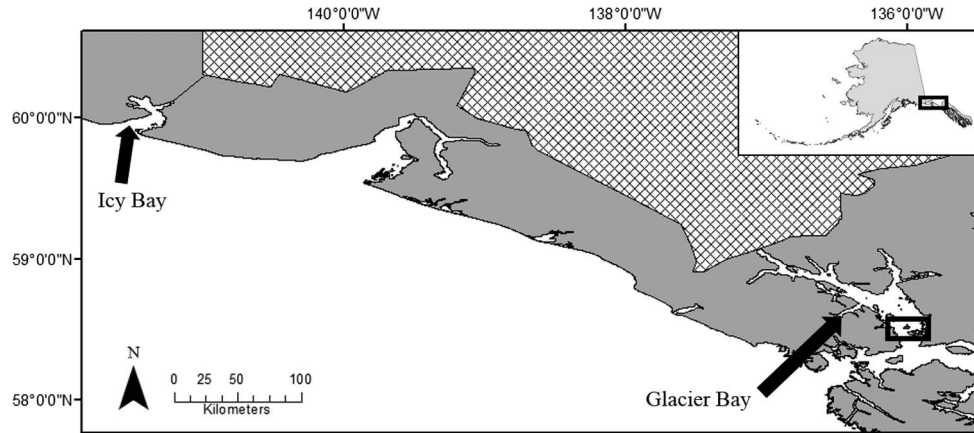


FIGURE 2. Map identifying the location of the *Brachyramphus* murrelet abundance survey, Icy Bay, Alaska, USA, July 2012, and field experiment, Glacier Bay National Park and Preserve, July 2013. The Sitakaday Narrows and Beardslee Islands within Glacier Bay National Park and Preserve are indicated by the black box.

rotated observers throughout the experiment to ensure that each person recorded observations under the full range of field conditions. Before each trial (each replicate of the experiment), the observers chose a group of murrelets on the water and recorded the estimated distance of the group from the survey vessel, Beaufort sea state (3 categories: glossy, rippled, and choppy), weather state (3 categories: <50% cloud cover, >50% cloud cover, and light rain or mist), murrelet group size, and murrelet behavioral response (3 categories: loafing, flushing, and diving) of each individual within the group. After noting these initial covariates, each observer independently made species identifications for each individual murrelet within the group. The captain then approached the group with the vessel at standard survey speed (<10 km hr⁻¹) while the observers independently recorded updated identifications at 20–40 m intervals. Throughout the entire process, the photographer took close-up photographs of the selected murrelet group, making an effort to keep all individuals within each frame. We limited group size to a maximum of 4 individuals to facilitate capturing all birds in each image. After completing the field experiment, we identified the true species of each individual using the photographs, from which we determined observer accuracy. We considered correct identification for each individual within each group separately; thus, identification had a binomial outcome (misidentification analysis: 0 = incorrect, 1 = correct; partial identification analysis: 0 = partially identified, 1 = identified to species, regardless of accuracy).

We applied the results from the field experiment to at-sea survey data collected in nearby Icy Bay, Alaska (60.0°N, 141.4°W; Figure 2), July 7–9, 2012. Icy Bay consists of a shallow outer bay, deep inner bay, and 4 radiating glacial fjords, each with an active tidewater glacier (Barclay et al.

2006). The marine surface area of Icy Bay is ~263 km², although, as a result of heavy ice floes and icebergs, only ~120 km² is open water that can be surveyed regularly. In contrast to most survey areas across their range, Kittlitz's Murrelets in Icy Bay consistently outnumber Marbled Murrelets (Kissling et al. 2011). Initially we had planned to conduct the identification field experiment in Icy Bay, but, due to logistical constraints, we completed the field experiment in Glacier Bay. Thus, for the purposes of assessing bias in abundance estimates due to varying identification rates, we assumed that the identification rates estimated in Glacier Bay were applicable to Icy Bay. We believe that this assumption was reasonable because of the similarities between the 2 study areas and the survey conditions experienced in each area.

We conducted at-sea surveys in Icy Bay following the protocol outlined in Kissling et al. (2007), the same protocol as was used for the field experiment. Briefly, 2 surveyors recorded all *Brachyramphus* murrelets within 300 m in front of and to an unlimited distance on either side of the boat. Along with each observation, surveyors recorded the perpendicular distance of the murrelet group from the transect line (m), murrelet group size, and environmental conditions such as sea and weather state. During surveys, Icy Bay was subdivided into 2 geographic strata, Main Bay and Taan Fjord, each with pelagic transects running perpendicularly to the shoreline (10 and 7 transects, respectively). Two observers surveyed 1 stratum each day; therefore, it took 2 days to complete a full survey of the bay. One observer had 5 yr of previous survey experience and the other observer had no murrelet survey experience. During this survey, the average group size was 1.5 (± 0.9 SD) and the maximum group size was 7 ($n = 1$); therefore, we do not expect that limiting the group size to 4 individuals during the field experiment caused bias in identification rates.

Statistical Methods

We performed all analyses using program Distance 6.2 release 1 (Thomas et al. 2010) and R 3.1.0 (R Development Core Team 2014). We fit generalized linear mixed models (GLMMs) using the `glmer` function from the `lme4` package (Bates et al. 2014). We used Akaike's Information Criterion (Akaike 1973) corrected for small sample sizes (AIC_c; Hurvich and Tsai 1989) to direct model selection, and assessed model fit via inspection of residuals.

Abundance estimation. We estimated the abundance of Kittlitz's and Marbled murrelets from the at-sea survey data collected in Icy Bay during the summer of 2012 following standard distance sampling methods (Buckland et al. 2001). We pooled all *Brachyramphus* murrelet observations recorded during the survey and truncated the observation distance at 250 m. We fit the truncated data to 2 global detection functions: the hazard-rate key function with a simple polynomial series expansion, and the half-normal key function with a Hermite polynomial series expansion. We estimated density, abundance, and encounter rate by geographic stratum and the encounter rate variance based on the empirical variance among transects. Variances of the abundance estimates were calculated using the delta method (Seber 1982). We assessed goodness-of-fit via inspection of Q-Q plots and Kolmogorov-Smirnov test values.

Misidentification analysis and application. We calculated misidentification rates for the entire field experiment, each experience level (0–5 yr), and each species (Kittlitz's or Marbled murrelet). We then developed GLMMs with a binomial error structure and a random effect for murrelet group to evaluate the relative contribution of explanatory variables to species misidentification (Hosmer and Lemeshow 2000). Due to issues with model convergence, we did not include a random effect for observer as was done in the partial identification analysis (see below). We selected the random effect for group because it accounted for relatively more variation than an observer random effect. One observer (0 yr of experience) committed no misidentification errors during the experiment and had to be excluded; this observer showed no variation in the response variable, resulting in singularity of the design matrix. Variables included in the models were sea state, weather state, observation distance, murrelet group size, murrelet behavior, and whether or not the group was composed of mixed species. We also included observer experience (number of previous survey years), which we treated as a categorical variable due to the small sample size of observers in this experiment ($n = 6$). For this analysis, we only included observations of birds identified to the species level (no partial identifications).

The candidate model set consisted of 13 models (including the global and null models), which we assessed using an information-theoretic approach (Burnham and

Anderson 2002). Using the most supported model, we predicted the probability that *Brachyramphus* murrelet groups recorded during the survey in Icy Bay were identified correctly. For example, for a group consisting of 3 individuals, using the fitted model parameter estimates, we computed the binomial probability of 4 identification scenarios: all identified correctly, 2 identified correctly and 1 misidentified, 1 identified correctly and 2 misidentified, and all misidentified. We adjusted the survey data to reflect the probability that groups were correctly or incorrectly identified by each observer, and then recalculated Kittlitz's and Marbled murrelet abundance estimates. We then compared these adjusted estimates to the original, unadjusted estimates.

Partial identification analysis. We calculated partial identification rates for the entire field experiment, each level of experience, and each species. We then modeled the relative contribution of the recorded covariates to partial identification of murrelets during the field experiment using GLMMs with a binomial error structure and including random intercepts for each observer and murrelet group to account for observer and group correlations (Hosmer and Lemeshow 2000). We evaluated the same explanatory variables as in the misidentification analysis; however, we included data from all murrelets observed during the field trials (even those misidentified). The candidate model set included 14 models, which were assessed using an information-theoretic framework (Burnham and Anderson 2002). We then used the results from the best-fit GLMM to predict the survey conditions in which observers were more likely to partially identify murrelets.

Partial identification allocation. Using the survey data from Icy Bay, we developed and compared 4 strategies to allocate partially identified murrelets to species. Each allocation method differed in either the spatial scale at which we estimated abundance or the spatial scale at which we allocated partially identified murrelets to a species. For the first strategy ("Global"), we used program Distance to estimate total *Brachyramphus* murrelet abundance and encounter rate by geographic stratum (Main Bay and Taan Fjord), and then we prorated partially identified murrelets to species based on the total proportion of each species observed during the entire survey. The second strategy ("Strata") was similar to the "Global" strategy, except that partially identified birds were allocated to a species based on the proportion observed per stratum. For the third method ("Total transect"), we estimated abundance and encounter rate by transect and allocated partially identified murrelets based on the overall proportion of each species observed during the entire survey. Lastly, we developed a strategy ("Individual transect") similar to the "Total transect" scenario, except that we apportioned partially identified

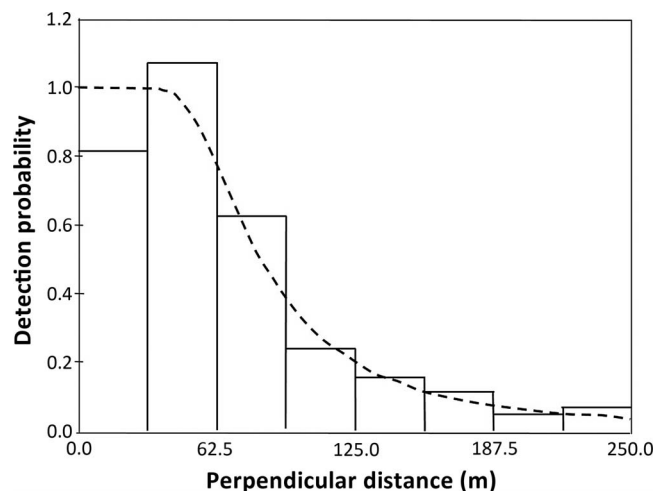


FIGURE 3. Estimated detection function for *Brachyramphus* murrelets resulting from an at-sea distance sampling survey in Icy Bay, Alaska, USA, July 2012.

murrelets based on the proportion of each species observed per transect.

For purposes of consistency and comparison with the original Icy Bay abundance estimates, for all 4 strategies we fit a global, hazard-rate detection function with a simple polynomial series expansion. We estimated the variance using the delta method. For the Global and Strata methods, we estimated the encounter rate variance empirically; however, for the Total and Individual transect strategies we assumed a Poisson variance structure due to the lack of spatial replication (Buckland et al. 2001). We assessed the results based on the calculated variance estimates and their associated assumptions.

Finally, we quantified the number of identified murrelets necessary to have confidence in the species-specific ratio used to inform the allocation of partially identified murrelets to the species level. We calculated the binomial probability variance over a range of species proportions (i.e. probability of success) and identification counts (i.e. number of successes). Lower variance values indicated higher precision and confidence in the species proportion used for partially identified murrelet allocation.

RESULTS

Abundance Estimation

We selected the hazard-rate detection function ($\Delta AIC = 0.00$) over the half-normal detection function ($\Delta AIC = 8.34$) as the best model to estimate detection probability of murrelets at sea (Kolmogorov-Smirnov $P = 0.31$). Our estimated effective strip width was 97 m. Detection probability was nearly 1 out to 50 m, beyond which it decayed rapidly with distance (Figure 3). Lower counts of murrelets near the transect line suggest that murrelets may

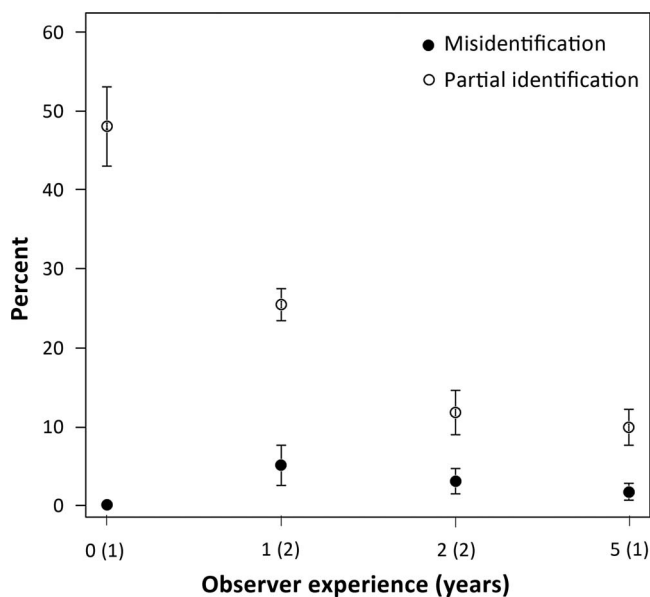


FIGURE 4. Summary of misidentification and partial identification rates (\pm SE) of *Brachyramphus* murrelets based on the experience level of 6 observers (number of observers in each experience level indicated in parentheses) during the identification field experiment in Glacier Bay, Alaska, USA, July 2013.

have been moving away from the line prior to detection, which could bias the resulting abundance estimates low (Figure 3; Buckland et al. 2001). This model resulted in a population estimate of 1,144 (\pm 348 SE) *Brachyramphus* murrelets in Icy Bay, with 1,071 (\pm 323 SE) Kittlitz's and 73 (\pm 36 SE) Marbled murrelets. These are the unadjusted abundance values used for comparison in the misidentification and partial identification analyses.

Misidentification Analysis and Application

The misidentification rate during the field experiment was 0.036 (\pm 0.004 SE, $n = 81$ of 2,228 observations of 183 murrelet groups), with experience-specific misidentification rates ranging from 0.000 to 0.052 (Figure 4). Observers misidentified *Brachyramphus* murrelets at similar rates (Kittlitz's = 0.034 ± 0.004 SE; Marbled = 0.037 ± 0.010 SE), indicating limited differences in species-specific identification.

Five GLMMs for identifying factors influencing misidentification of murrelets during surveys received model likelihood values ≥ 0.10 (Table 1). Four of these models included observer experience and 1 other parameter (behavior, weather state, distance, or sea state), and 1 model included only observer experience. Observer experience was the only parameter in any model with a profile confidence interval that did not overlap 0 (Table 2), therefore we selected the observer experience only model ($\Delta AIC_c = 0.00$) as the most supported (area under the receiving operating characteristic curve [AUC] = 0.61).

TABLE 1. Model selection results for the *Brachyramphus* murrelet identification GLMM analyses, Glacier Bay, Alaska, USA, July 2013. Models presented are those with model likelihood values ≥ 0.10 and the null model. Models are ranked based on the difference from the top model in second-order Akaike's Information Criterion (ΔAIC_c). Likelihood is the probability of the data given a model, k is the number of model parameters, and Dev is the model deviance.

Analysis	Model	ΔAIC_c	Likelihood	k	Dev
Misidentification	A. Observer experience	0.00 ^a	1.00	4	367.33
	B. Observer experience + Behavior	0.74	0.69	6	364.06
	C. Observer experience + Weather state	1.80	0.41	5	367.13
	D. Observer experience + Distance	1.82	0.40	5	367.14
	E. Observer experience + Sea state	3.20	0.20	6	366.52
	F. (Null)	43.46	0.00	1	414.81
Partial identification	G. Observer experience * Distance + Sea state + Behavior	0.00 ^b	1.00	9	1,749.53
	H. Observer experience * Distance + Sea state + Behavior + Group size	1.46	0.48	10	1,748.97
	I. Observer experience + Distance * Sea state + Behavior	3.54	0.17	9	1,755.09
	J. Observer experience + Distance + Sea state + Behavior	4.10	0.12	9	1,759.68
	K. (Null)	853.45	0.00	2	2,625.11

^aThe AIC_c value for the top model = 375.35.

^bThe AIC_c value for the top model = 1,777.67.

The results from this model indicated that the probability of correct murrelet identification increased with increasing observer experience (Table 2). Model results also indicated that the probability of correct identification for each individual murrelet was essentially 1 for the baseline level of observer experience (intercept = 1 yr of previous experience; Table 2). When this model was applied to the data previously collected during the Icy Bay survey, adjusted abundance estimates based on an observer with 1 yr of experience resulted in a change of -0.01% for Kittlitz's and $+0.12\%$ for Marbled murrelets from the unadjusted estimates, while adjusted estimates based on an observer with 5 yr of survey experience led to only a -0.0001% and $+0.0013\%$ change, respectively.

Partial Identification Analysis

The overall partial identification rate during the field experiment was $0.21 (\pm 0.01 \text{ SE}; n = 650 \text{ of } 3,082 \text{ observations of } 191 \text{ murrelet groups})$, with experience-specific partial identification rates ranging from 0.10 to 0.48 (Figure 4). Observers partially identified Marbled Murrelets proportionally more than Kittlitz's Murrelets (Kittlitz's = $0.18 \pm 0.01 \text{ SE}$; Marbled = $0.22 \pm 0.02 \text{ SE}$; $P = 0.001$).

Four models for evaluating the factors influencing partial identification of murrelets received model likelihood values ≥ 0.10 (Table 1). The most supported model ($\Delta AIC_c = 0.00$) included terms for sea state, distance, observer experience, behavior, and the interaction between distance and observer experience. The second-most supported and only other model with $\Delta AIC_c < 2$ included all of the above terms with the addition of group size ($\Delta AIC_c = 1.46$). Choppy sea state, distance, observer experience (2 and 5 yr), and flushing behavior were the

only parameters in either model with profile confidence intervals that did not overlap 0 (Table 3).

Based on these results, we selected the model including sea state, distance, observer experience, behavior, and the interaction between distance and observer experience as the most supported model ($AUC = 0.87$). The results from this model indicated that identification to the species level decreased in choppy sea states and when murrelets demonstrated diving behavior, and increased when murrelets demonstrated flushing behavior (Table 3). The interaction between observer experience and distance suggested that as both distance and observer experience increased, the probability of identification to the species

TABLE 2. Coefficient estimates and lower and upper profile confidence limits (LCL and UCL, respectively) from all candidate models in the misidentification analysis with $\Delta AIC_c \leq 2$ (Table 1). Models are referenced using the alphabetical letters from Table 1. Observer experience was the only parameter in any model with confidence intervals that did not overlap 0.

Model	Parameter (factor level)	Estimate	LCL	UCL
A	Intercept	9.26	7.50	11.81
	Observer experience (2 yr)	2.40	0.50	5.15
	Observer experience (5 yr)	4.51	2.80	7.14
B	Intercept	9.20	7.33	11.69
	Observer experience (2 yr)	2.57	0.63	5.39
	Observer experience (5 yr)	4.67	2.92	7.36
	Behavior (flushing)	1.09	-0.15	2.52
C	Behavior (diving)	0.35	-0.61	1.39
	Intercept	9.58	7.52	12.62
	Observer experience (2 yr)	2.41	0.51	5.14
	Observer experience (5 yr)	4.51	2.80	7.13
	Weather state (cloudy)	-0.63	-3.52	2.44
D	Intercept	9.35	7.41	11.82
	Observer experience (2 yr)	2.44	0.53	5.21
	Observer experience (5 yr)	4.55	2.83	7.20
	Distance	-0.09	-0.51	0.32

TABLE 3. Coefficient estimates and lower and upper profile confidence limits (LCL and UCL, respectively) from all candidate models in the partial identification analysis with $\Delta AIC_c \leq 2$ (Table 1). Models are referenced using the alphabetical letters from Table 1. Parameters in bold font indicate those with profile confidence intervals that do not overlap 0.

Model	Parameter (factor level)	Estimate	LCL	UCL	
G	Intercept	0.46	-1.42	2.14	
	Sea state (rippled)	0.06	-0.66	0.78	
	Sea state (choppy)	-1.32	-2.31	-0.35	
	Distance	-2.34	-2.84	-1.88	
	Observer experience (1 yr)	1.77	-0.40	4.01	
	Observer experience (2 yr)	4.05	1.79	6.37	
	Observer experience (5 yr)	4.86	2.25	7.53	
	Behavior (flushing)	1.87	1.06	2.81	
	Behavior (diving)	-0.49	-1.07	0.11	
	Distance: Observer experience (1 yr)	0.28	-0.21	0.78	
	Distance: Observer experience (2 yr)	-0.52	-1.19	0.14	
	Distance: Observer experience (5 yr)	-0.55	-1.32	0.18	
	H	Intercept	0.13	-1.92	2.14
		Sea state (rippled)	0.06	-0.64	0.78
Sea state (choppy)		-1.33	-2.31	-0.36	
Distance		-2.33	-2.83	-1.87	
Observer experience (1 yr)		1.76	-0.41	4.01	
Observer experience (2 yr)		4.04	1.78	6.36	
Observer experience (5 yr)		4.85	2.24	7.52	
Group size		0.17	-0.28	0.61	
Behavior (flushing)		1.88	1.06	2.82	
Behavior (diving)		-0.48	-1.06	0.11	
Distance: Observer experience (1 yr)		0.27	-0.21	0.78	
Distance: Observer experience (2 yr)		-0.53	-1.20	0.13	
Distance: Observer experience (5 yr)		-0.56	-1.34	0.17	

level decreased, although the effect size of this parameter was quite small and confidence intervals overlapped 0. Using this fitted model, we predicted that the distance at which individual observers were equally likely to identify a murrelet to the species level or only to the genus level varied from ~90 to 250 m depending on conditions and experience level (Figure 5).

Partial Identification Allocation

The 4 partially identified *Brachyramphus* murrelet allocation strategies resulted in similar total *Brachyramphus* and species-specific abundance estimates, but variable estimates of variance. There were minimal differences between the Global and Strata strategies (Table 4), because the proportion of *Brachyramphus* murrelets in each stratum of Icy Bay was approximately equal during the survey (Main Bay = Kittlitz's 15:1 Marbled, Taan Fjord = Kittlitz's 12:1 Marbled). Allocating partially identified murrelets by the proportion observed per transect resulted

in a 4% decrease in Kittlitz's Murrelet abundance and a 65% increase in Marbled Murrelet abundance (Individual transect) compared with allocation by the overall proportion (Total transect; Table 4).

The binomial probability variance over a range of species proportions and identification counts displayed a wide range depending on the skew in the species ratio and the number of identified individuals (Figure 6). High variation was associated with lower numbers of identified birds and more balanced species ratios. Low variation, thus higher confidence in the observed proportion, was associated with higher numbers of identified individuals and less balanced species ratios. When species ratios were highly skewed, variation was low with as few as 20–30 identified individuals. However, when species ratios were approximately equal, identification of 40–60 individuals resulted in higher confidence in the observed ratio used to inform species-specific allocation of partially identified murrelets.

DISCUSSION

Threatened and endangered species pose a complex challenge for monitoring and management. Rarity itself constrains quick or simple collection of data; therefore, managers must often make policy or management decisions despite large statistical or biological uncertainty. Fortunately, many recent studies related to the sampling of rare or elusive species have led to new advances in the field. For example, Reynolds and Renner (2014) modified traditional occupancy models to estimate the extent and density of crevice-nesting seabirds while accounting for imperfect detection. Further, Sanders and Mennill (2014) evaluated new techniques for monitoring the abundance of nocturnal migrants by recording and analyzing nocturnal flight calls.

This is the first study that we are aware of that directly quantifies both misidentification and partial identification rates and the factors contributing to each rate during at-sea surveys. Despite the recent concern over identification errors and their impact on the interpretation of Kittlitz's Murrelet abundance estimates (Kirchhoff 2011, Hodges and Kirchhoff 2012), we found that misidentification was low in this system. Additionally, in contrast to several recent studies (e.g., Hull et al. 2010, McClintock et al. 2010), misidentification errors did not bias abundance estimates. However, due to the small number of observers ($n = 6$) tested in this experiment, we advise caution when extrapolating these results to other surveys. Although we found relationships between misidentification and observer experience only, this may not necessarily mean that relationships with observation distance, murrelet behavior, sea state, weather state, or group size do not exist. Misidentification was a relatively rare event during our

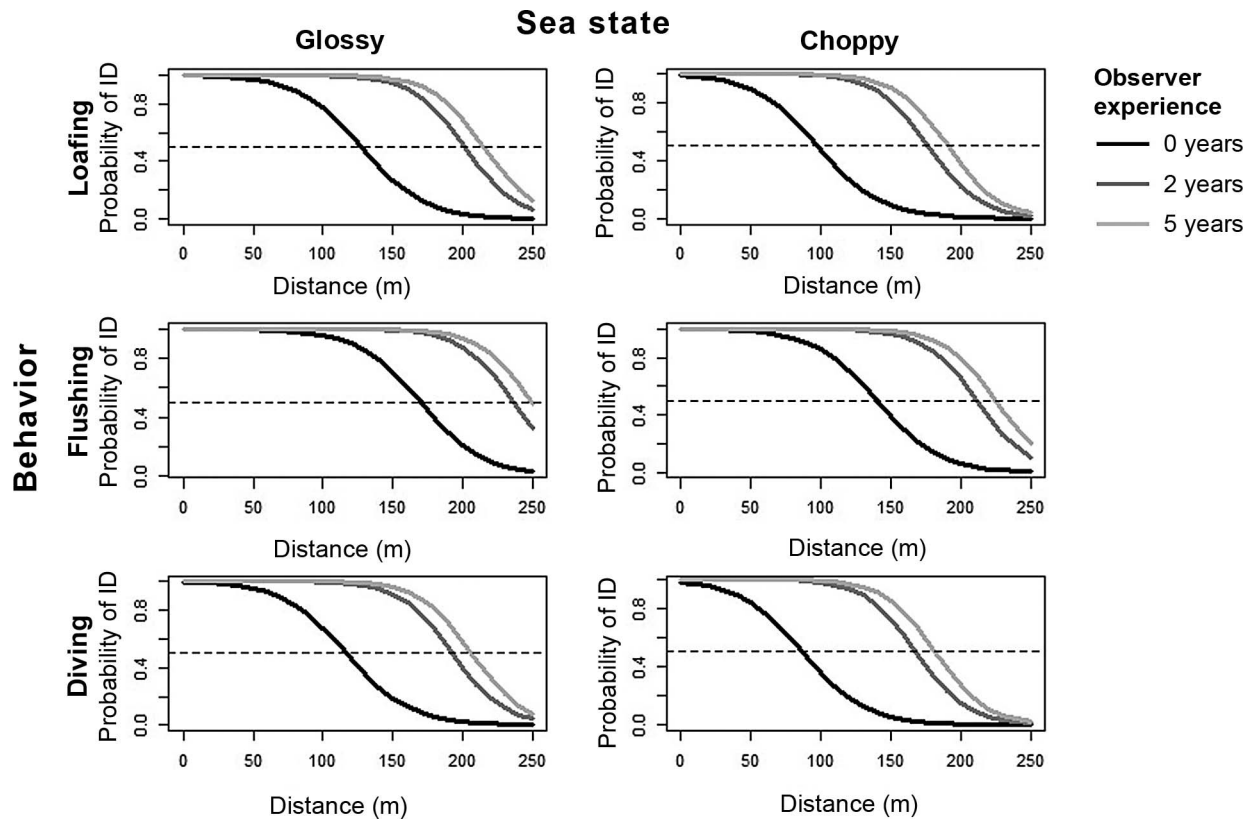


FIGURE 5. The probability of observers of varying experience levels (0, 2, and 5 yr) identifying a *Brachyramphus* murrelet to the species level under 2 sea states (glossy, choppy) and 3 murrelet behavioral responses (loafing, flushing, diving) across a range of observation distances (m), Glacier Bay, Alaska, USA, July 2013. The sea states included represent the extremes of sea conditions encountered during surveys, thus illustrating the full impact that sea conditions can have on the identification of murrelets. A maximum distance of 250 m was tested during the field experiment. Dashed horizontal lines delineate a 50% probability of species identification.

field experiment, and therefore we may not have a large enough sample size to evaluate the significance of these variables fully, despite a large number of observations ($n = 2,228$ observations of 183 murrelet groups). Regardless, the infrequency of misidentification and the resulting lack of statistical power to detect these relationships clarify and provide some support for *Brachyramphus* murrelet abundance estimates from recent history that used similar survey methodologies, including observer training programs.

However, these estimates of misidentification may be biased low for a number of reasons. First, we lacked experimental data for observations made during rainy conditions, which we would expect to increase misidentification rates. Although coastal Alaska is characterized by high precipitation and surveys often are conducted in the rain, the 6-day period during which we conducted our field experiment was unusually sunny (as was the entire summer of 2013) with no precipitation, so we were unable to test this hypothesis. Second, observers focused on a single murrelet group at a time during the field

experiment. During surveys, depending on the density of murrelets, observers often have to make very rapid identification decisions and then move on or risk missing groups on or close to the survey line. Allowing only quick

TABLE 4. Estimates of abundance of Kittlitz’s and Marbled murrelets based on a survey in Icy Bay, Alaska, USA, 2012. We allocated partially identified murrelets to species (K = Kittlitz’s, M = Marbled) based on the overall proportion of each species observed during the survey (Global, Total transect), the proportion per stratum (Strata), or the proportion observed per transect (Individual transect). We estimated abundance (\hat{N}) and encounter rate by stratum (Global, Strata) or by transect (Total transect, Individual transect). All 4 strategies resulted in similar total abundance estimates, but variable estimates of variance (SE).

	\hat{N} (Total)	SE (Total)	\hat{N} (K)	SE (K)	\hat{N} (M)	SE (M)
Global	1,144	348	1,071	327	73	36
Strata	1,144	347	1,071	328	73	36
Total transect	1,126	135	1,054	129	72	30
Individual transect	1,126	135	1,007	127	119	82

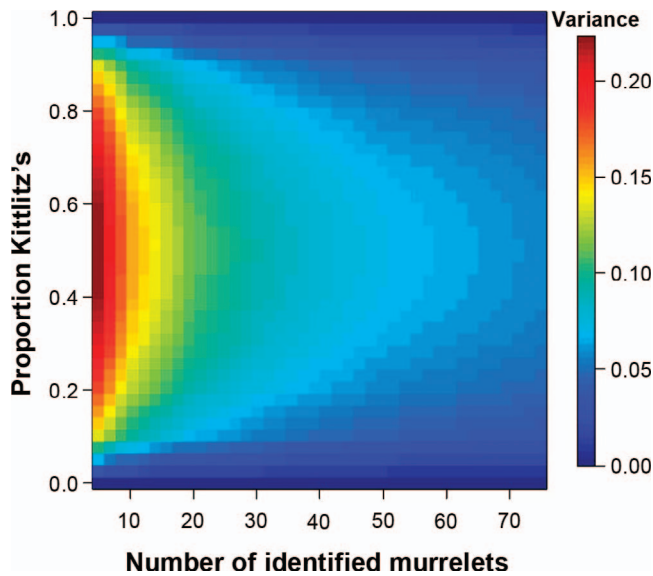


FIGURE 6. The binomial probability variance for a range of species ratios and number of murrelet individuals identified to the species level. Cooler colors indicate lower variance and higher confidence in the resulting proportions, while warmer colors indicate higher variance and less confidence in the proportions.

glimpses of each murrelet group could increase identification errors. Finally, misidentification could have been lower due to observer expectancy bias. The observers participating in the field experiment knew that they were being evaluated for accuracy. Mills and Knowlton (1989) demonstrated that observers performed better when they knew that they were being tested compared with when they were unaware that they were being tested. Given the setup and planning for the current study, we were unable to avoid this issue.

Because our misidentification rates may be biased low, misidentification could potentially have larger impacts on abundance estimates than we were able to demonstrate in the current study. However, these results do provide insight into the factors contributing to misidentification of *Brachyramphus* murrelets and indicate methods for minimizing the risk of misidentification during surveys. Observer experience best explained variation in misidentification rates. Therefore, our results emphasize the importance of rigorous observer training for increasing consistency and confidence in species identification across survey areas.

The partial identification rate across all observers was well within the range of rates previously reported for murrelet surveys (range: 0.00–0.89; Day 2011). As expected, partial identification increased in rougher sea states. Partial identification also increased when murrelets demonstrated diving behavior, but decreased when murrelets demonstrated flushing behavior. As murrelets flush off

the water and take flight they fan out their tail feathers for just a few seconds. During this time, it is possible for an observer to see the white outer retrices of the Kittlitz's Murrelet (Marbled Murrelets have only brown retrices). Seeing the flash of white on the tail is the easiest and most definitive way to confirm species identification in the field, as reflected by our results. The interaction between observer experience and distance indicated that observers with more experience were more likely to partially identify murrelets at greater distances. This is counterintuitive to what we would have expected, although the effect size for this term was small and the confidence intervals around the parameter estimate overlapped 0 (Table 3). When using this model for predictive purposes, we found that the distance at which observers had an equal probability of identifying a murrelet to the species level or only to the genus level varied widely (90–250 m) depending on the observers' level of experience and conditions (Figure 5). The maximum distance tested during the field experiment was 250 m, so inference beyond this distance is limited.

It is difficult to assess the best approach for allocating partially identified individuals to the species level because we cannot know true population abundance. Our results suggest that murrelets should be allocated to species based on the proportion observed per geographic location (Strata in our design) if the survey site is spatially subdivided. If not, we recommend apportioning partially identified murrelets based on the overall species ratio observed during the survey. In this analysis, the Global and Strata results were essentially the same because the proportion of murrelets observed within each stratum was almost equivalent. However, this may not always be the case. Kittlitz's and Marbled murrelets generally are distributed differently within a study area depending on habitat characteristics (Day et al. 1999, 2003). For example, Kittlitz's Murrelets prefer turbid glacial- or glacial stream-influenced habitat, whereas Marbled Murrelets prefer glacially unaffected habitat (Day et al. 2003). Therefore, species proportions across strata potentially could be very different, depending on the habitat characteristics of the survey site. If this is the case, we suggest using habitat type as the basis for delineating strata.

We do not recommend allocation of partially identified individuals based on the proportion observed per transect for 2 reasons. First, the variance estimated from this method is likely underestimated because murrelets are not distributed randomly (Buckland et al. 2001), but instead are distributed relative to the habitat characteristics of the study site (Day et al. 1999, 2003). Thus, this method provides a false level of confidence in the estimated abundance. Second, apportioning murrelets based on the proportion observed per transect may use too fine a spatial scale. For example, this method could not be used if the

only observations on a given transect were recorded as partially identified murrelets. Allocation based on the proportion observed per transect may be viable with very long transect lines that allow for many detections of the target species. While this was not the case for murrelets, it may be possible if the method is applied to other species (e.g., other seabirds in an open ocean setting).

An alternative strategy that may be considered for future work is to assign partially identified individuals to species based on the species ratio observed within a certain distance of the vessel. Because the probability of identification declines with increasing distance, this method would ensure that only reliable identifications are used to inform species-specific abundance estimates. We did not include this strategy in the current analysis because, during the Icy Bay surveys, only the perpendicular distance of the murrelet group from the transect line was recorded, not the angle and distance of the murrelet group from the survey vessel, which was more reflective of the method used in the field experiment.

We pooled all observations for Kittlitz's and Marbled murrelets for the regression analyses due to small sample sizes, although environmental and observational factors may drive variation in identification rates of each murrelet species differently. However, because the 2 species are behaviorally and morphologically similar, the mechanisms driving misidentification and partial identification are likely similar. Additionally, although observers partially identified Kittlitz's and Marbled murrelets at slightly different rates, it is difficult to assess whether these differences are related to species-specific traits or to the skewed sample sizes for each species resulting from the differences in the population sizes of Kittlitz's and Marbled murrelets in Glacier Bay (Sergeant et al. 2014). If there are indeed species-specific differences in identification, our results would suggest that allocation based on observed proportions may not be appropriate. Research opportunities exist to further evaluate this issue, ideally within a system in which the species ratios are flipped. However, Marbled Murrelets are more abundant than Kittlitz's Murrelets in most places where the 2 species overlap, including Glacier Bay. Therefore, the results of our field experiment are applicable to most study areas across coastal Alaska.

We provide the following suggestions for future at-sea survey efforts. First, modify the scanning width (the distance in front and to either side of the survey vessel to which observers record individuals) depending on observer experience level and sea state for a given survey. Results from the partial identification analysis suggest that, even during calm sea conditions when murrelets are just sitting on the water, observers are unlikely to identify a murrelet to the species level at distances greater than ~130 m for less experienced observers and ~220 m for more

experienced observers. However, these distances would be expected to change depending on the characteristics of the target species. With inexperienced observers or rough seas, it would be prudent to focus efforts on distances closer to the vessel to ensure that all individuals are detected on or close to the survey line, and also to promote higher rates of identification. This would be good practice for any distance sampling survey, not just those carried out at sea.

Second, ensure that a sufficient number of individuals is recorded reliably to the species level to have high confidence in the species proportions used to inform species-specific abundance estimates (Figure 6). In this particular system, in an area with a heavily skewed species composition (e.g., 0.85), identification of ~30 murrelets would result in a robust species proportion, while in an area with a more balanced species composition (e.g., 0.50), identification of ~60 individuals would be necessary.

Finally, conduct rigorous and high-quality observer training, such as that described by Raphael et al. (2007), before and during surveys to increase confidence in species identification. Observer experience is an important driver of both misidentification and partial identification in this system and others (e.g., McClintock et al. 2010, Shea et al. 2011). Fortunately, it is also the factor that we are most able to control and improve upon. Methods similar to those used in the field experiment could be modified to evaluate observer training and determine whether observers are qualified to perform at-sea surveys. Further, development of a standardized training program would provide consistency and quality control across surveys and improve comparability of results across the range of the species of interest.

Although the methods used for this field experiment were tailored to the *Brachyramphus* murrelet study system, these techniques could be modified for use in any at-sea survey scenario to measure identification rates and identify the factors influencing those rates. Results may reveal important patterns or relationships that could provide guidelines for adjusting survey protocols to increase confidence in species identification and thereby increase the precision of abundance estimates, especially for rare species. Additionally, a better understanding of the magnitude of identification errors may provide insight into and gauge reliability of historical survey results.

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