A 31-YEAR TIME SERIES OF AT-SEA COUNTS SHOWS A NON-SIGNIFICANT DECLINE OF MARBLED MURRELETS AT LASKEEK BAY, HAIDA GWAII, 1990–2020

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ABSTRACT

PATTISON, V., BERTRAM, D.F., PASTRAN, S.A., GASTON, A.J., DICKSON, R.D. & DREVER, M.C. 2024. A 31-year time series of at-sea counts shows a non-significant decline of Marbled Murrelets at Laskeek Bay, Haida Gwaii, 1990–2020. *Marine Ornithology* 52: 141–147.

The Marbled Murrelet *Brachyramphus marmoratus* breeds and overwinters along the coast of British Columbia, Canada, and is listed as Threatened under the Canadian *Species at Risk Act*. Understanding population trends for this seabird species is important for management and recovery, yet long-term time-series data for Marbled Murrelet abundance are rare. We update trends and annual fluctuations of Marbled Murrelet numbers derived from at-sea counts in Laskeek Bay, Haida Gwaii, on the north coast of British Columbia, 1990–2020. We found a non-significant negative trend (−1.55% per year). Counts varied seasonally and peaked in early June; counts also varied with distance from shore, with the highest numbers occurring within 1 km of shore. Importantly, a change in survey protocol after 1996, which reduced the transect width from 400 m to 100 m, resulted in lower counts, and we found that counts were 2.7 times greater when wider transects were surveyed. Inter-annual fluctuations in counts were high, but we found no significant relationships between bird counts and either large-scale oceanographic cycles or more localized indicators of ocean productivity. Compared to previous analyses of this dataset, which showed strong declines, the absence of a trend in at-sea counts is more in line with trends derived from systematic radar counts conducted within the Haida Gwaii conservation region over a similar period (−2.8% per year). Our study emphasizes the need to investigate fluctuations in at-sea counts more closely to understand what may be driving peaks in at-sea counts, including possible movement of birds between regions.

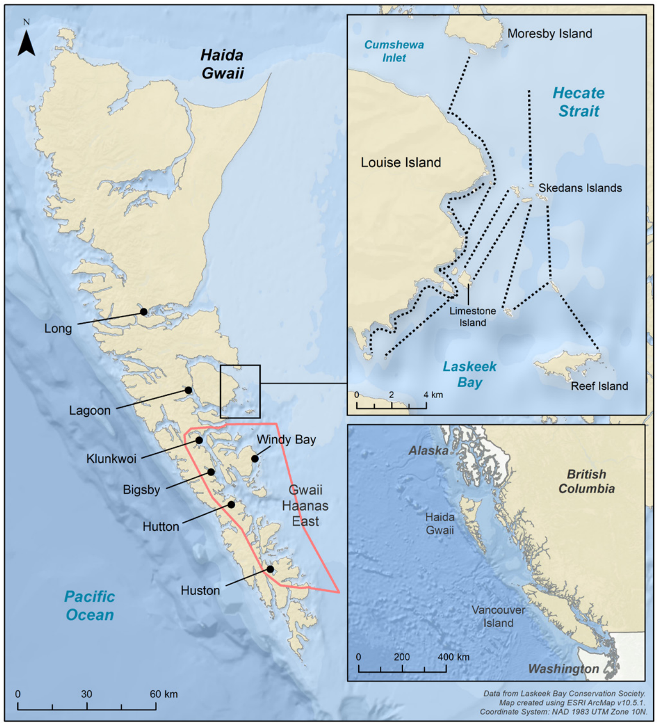
Key words: *Brachyramphus marmoratus*, population trends, at-sea counts, Haida Gwaii, movements

INTRODUCTION

Identifying trends in populations over time is challenging when dealing with a widespread, low-density seabird species, such as the Marbled Murrelet *Brachyramphus marmoratus* (hereafter, murrelets). For this species, understanding how many birds are present in a region and whether populations are changing is especially challenging because, unlike many seabirds, Marbled Murrelets are not colonial breeders (Raphael *et al.* 2015). Instead, they nest individually in tall trees that are widely spaced, making enumeration of nest sites an impractical population-monitoring method (Wong *et al.* 2008, Lorenz & Raphael 2018). In addition, the species' range is continuous from Alaska to California, including both the breeding and non-breeding seasons (Piatt *et al.* 2007). Thus, distinguishing true population trends versus movement of birds is challenging. In Canada, this species is listed as Threatened under the *Species at Risk Act* (COSEWIC 2012), and a Recovery Strategy has been developed (ECCC 2023). In the province of British Columbia (BC), the archipelago of Haida Gwaii makes up one of six conservation regions laid out by the Canadian Marbled Murrelet Recovery Team (Bertram *et al.* 2015). Although historic population estimates for the province are unreliable due to limited data, Burger (2007) indicated that the Marbled Murrelet population in the Haida Gwaii conservation region could be over 20% of the total provincial population. Therefore, knowledge of Marbled Murrelet trends in this region is essential for effective province-wide management for this species.

In BC, long-term monitoring efforts for Marbled Murrelets include at-sea surveys (Zharikov & Yakimishyn 2020) and radar counts of birds entering the forest when breeding (Burger *et al.* 2004, Bertram *et al.* 2015, Drever *et al.* 2021). Although radar counts have been identified as the most effective method for monitoring Marbled Murrelet populations in BC (Arcese *et al.* 2005), at-sea surveys are important for understanding marine distribution, annual fluctuations in breeding effort, and large-scale movements of this species. Long-term at-sea datasets in BC are rare. Marbled Murrelet counts at sea tend to fluctuate widely, demonstrating large peaks in some years. These fluctuations are often attributed to marine-habitat conditions (Yen *et al.* 2004, McIver *et al.* 2021), including large-scale oceanographic cycles such as El Niño Southern Oscillation (Lorenz & Raphael 2018). Marbled Murrelet survival and breeding success are influenced by fluctuations in prey availability, which can be related to ocean-climate variation (Lorenz & *Raphael* 2018). In turn, the number of birds observed at sea can be affected. Birds may also relocate in response to changes in prey availability, influencing how many birds are counted annually in different habitats within one region (Pastran *et al.* 2021) or in different survey regions (Raphael *et al.* 2015).

The Laskeek Bay Conservation Society (LBCS) has been conducting counts of marine birds, including Marbled Murrelets, in Laskeek Bay on the east coast of Haida Gwaii for over 30 years (Fig. 1). This dataset is now the longest continuous time series of annual seabird counts in BC, and these data informed the most recent assessment of the status of Marbled Murrelets in Canada (COSEWIC 2012); since the assessment's publication, 11 years of data have been added to this dataset. We also identified a change in the field methods used to collect the LBCS data: the width of the strip transects used during surveys was reduced in 1997. Previous studies reporting steep declines in numbers of Marbled Murrelets for this area (−14.6% per year; Burger *et al.* 2007) may have been unintentionally inflated if the authors were unaware of this method change. Due to high inter-annual variability, trends in bird numbers calculated for this area have varied over time (Burger 2002), and declining bird numbers appear to be driven by the counts in the 1990s (Burger *et al.* 2007). Here we provide an updated analysis of this dataset, accounting for the newly recognized change in survey protocols and incorporating 11 years of new data. We focused on three questions: 1) Has there been a long-term change in numbers of Marbled Murrelets counted in Laskeek Bay, based on the updated data and methods? 2) Does this new analysis change our understanding of Marbled Murrelet trends over the past 31 years in the Haida Gwaii conservation region? 3) Do ocean conditions cause the high inter-annual variability in murrelet counts in Laskeek Bay?



Data from Laskeek Bay Conservation Society.
Map created using ESRI ArcMap v10.5.1.
Coordinate System: NAD 1983 UTM Zone 10N.

Fig. 1. Map of Haida Gwaii, British Columbia (BC), Canada. Black points shown throughout Haida Gwaii are Marbled Murrelet *Brachyramphus marmoratus* radar monitoring stations. The orange outline shows Gwaii Haanas East, the region from which SST and Chl *a* satellite data were summarized. Bottom inset: Location of Haida Gwaii in relation to the rest of the BC coast. Top inset: Transect locations in Laskeek Bay. Transects (dashed black lines) have been surveyed since 1990 to count marine birds.

METHODS

The LBCS seabird at-sea survey program began in 1990 and is the longest-running annual survey for marine birds in BC. The dataset now spans three decades, from 1990 to 2020 (Pattison *et al*. 2024). Researchers use a small open boat (5.0–5.5 m in length) to survey a set of transects between the small islands of Laskeek Bay and along the shoreline of Louise Island in the spring and summer every year (Fig. 1), at approximately two-week intervals. At-sea surveys are only one part of the monitoring and research work that LBCS carries out during their field season. Therefore, the timing of the surveys was dependent on coordination with other field projects and was not solely based on Marbled Murrelet biology. All birds and marine mammals seen are recorded during the surveys. The exact location of transects surveyed over time, the number of surveys completed, and the timing of the surveys have remained relatively consistent; since 2005, they have been standardized. The complete survey route (67.6 km), surveyed over one to two days, is now conducted annually from early May to mid-July. In some years (1990 and 1993 in particular), surveys were spread over many days. For additional survey methods, see Pastran *et al.* (2021). In this analysis, we used only counts of Marbled Murrelets seen on the water. Before 1998, birds seen flying were not recorded consistently, and the proportion of Marbled Murrelets recorded in flight each year was low (between 0% and 13%). Consequently, we removed observations of flying birds from all years.

A significant methodological change occurred in 1997, when total strip-transect width was reduced from 400 m (i.e., 200 m on each side of the boat) to 100 m (i.e., 50 m on each side of the boat). Due to the wider transects in earlier years (1990–1996), it is likely that observers counted more birds. In this analysis, we attempt to correct for transect width in order to use the full dataset from 1990 to 2020. We re-analyzed the Laskeek Bay Marbled Murrelet counts to update previous analyses (Piatt *et al.* 2007, COSEWIC 2012) with the additional 11 years of data (2010–2020). To determine if there was a significant linear trend in counts over time, we constructed a baseline trend model using generalized linear mixed-effects models (GLMMs) with a negative binomial distribution. We included Transect Identifier and Year as random effects, to allow for repeated observations. We included Day of Year as a fixed effect in a quadratic equation (Quadratic Day of Year), to account for the changes in the number of birds seen on the water throughout the breeding season (Bertram *et al.* 2015, Drever *et al.* 2021)—for example, the number of birds seen on the water will increase from May to June as birds shift from incubating eggs to feeding young (Piatt *et al.* 2007). To accommodate the decrease in transect width from 1997 onward, we included Transect Width as a fixed-effect factor. The transects varied in distance from Louise Island, which is the nearest large landmass. Murrelets are known to be present in higher densities closer to shore (Becker *et al.* 1997, Pastran *et al.* 2021); therefore, we also included the Distance to Louise Island (from the middle of each transect) as a fixed effect. As shown in Fig. 1, some transects are surveyed along the shore of Louise Island. These are set at a standard distance of 200 m from shore, while the straight-line transects vary in distance to shore at their mid-point, between 1.0 and 7.4 km.

We developed similar GLMMs to examine how Marbled Murrelet numbers in the study area relate to large-scale oceanographic variability, as expressed by the Pacific Decadal Oscillation (PDO; NOAA 2023a) and the Multivariate ENSO Index (MEI; NOAA

2023b). For both indices, we averaged the monthly values from January to April to indicate pre-breeding season ocean conditions. The Pearson Correlation Coefficient between these two measures was 0.53, suggesting that they are not highly correlated and that using both in the model would be beneficial. We also included both sea-surface temperature (SST) as a more localized measure of ocean conditions and chlorophyll *a* (Chl *a*) concentration as an index of primary productivity. We used satellite data from Fisheries and Oceans Canada (Devred *et al.* 2021). These data were averaged over Gwaii Haanas East, a region that is located slightly south of Laskeek Bay (Fig. 1) but experiences similar ocean conditions (A. Hilborn pers. comm.). SST and Chl *a* data were averaged over April and May as an indication of spring bloom conditions. Chl *a* data were available only from 2003 to present. We ran all models using the "glmmTMB" package (Brooks *et al.* 2017) in the R environment (R Core Team 2022).

RESULTS

Trend analysis

We used the murrelet count per transect per day as our population index. The complete dataset comprised counts over 19 different transects and 31 years, for a total of 2269 replicates (transect-days). The baseline trend model that incorporated the change in transect width and other variables known to influence Marbled Murrelet counts at sea (i.e., Day of Year, Distance to Louise Island) did not detect a significant trend from 1990 to 2020 using the convention of alpha = 0.05 (Fig. 2). The calculated trend in the number of birds expected per kilometre of transect was −1.55% per year ($P = 0.261$, Table 1). We compared the trend model to a simpler model that did not include a trend parameter (i.e., Year was considered as a fixed effect). We found that the model without a trend had marginally higher Akaike information criterion (AIC) values than the model having the trend (AIC of baseline model = 11 004.7; AIC of trend model = 11 005.4), which indicated weak support for including a trend estimate. We also compared the trend model to one that included the interaction between year and width, to see if the two survey methods (wider vs. narrower width) should be modelled separately. There was no support for the model that included separate trends for the two different widths; therefore, we retained the simpler model that investigated trends over the whole period.

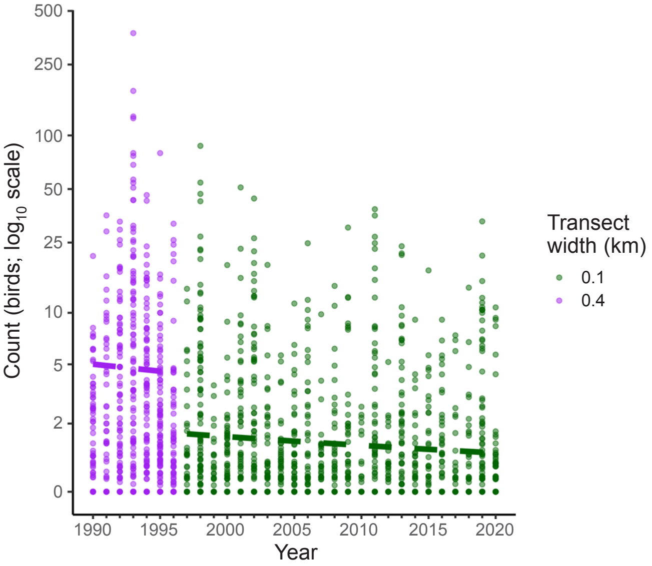


Fig. 2. Raw count data and model results from a mixed-effects trend model analyzing the change in Marbled Murrelet *Brachyramphus marmoratus* counts over time in Laskeek Bay, British Columbia, Canada. Points represent the count of murrelets per kilometre for each individual transect on each day the transect was surveyed in a given year. The non-significant trend line is shown as a dashed line. A change in transect width in 1997 was incorporated into the model as a fixed-effect factor. Note that y-axis scale is $\log_{10}$, and a pseudo-log transformation was used to account for zero-value data points.

The change in survey protocol resulted in fewer birds counted on the water. The difference in the number of birds counted in the earlier years, when the transects were wider, was significant ($P = 0.012$) and positive. This suggests that 2.7 times the number of birds per kilometre could be expected with the wider transects (Table 1). The standard deviations of the effects of Transect and Year were found to be roughly equal when accounting for the random effects. This indicates that the variance across the years and the variance across the transects were similar to each other.

Variations over time and space

From the GLMM, we predicted the mean number of Marbled Murrelets counted annually. We found that counts fluctuated widely and that some years had distinct peaks (Fig. 3). The peaks in abundance were present even after controlling for variability from methodological changes, survey date, and distance to shore. Estimated yearly linear densities (birds per kilometre) and standard errors are also given in Table A1 in the Appendix (available online).

Counts of Marbled Murrelets in the Laskeek Bay area were lower further from shore, measured as the distance from the middle of

TABLE 1
Trend model results from the generalized linear mixed-effects models of Marbled Murrelet *Brachyramphus marmoratus* counts in Laskeek Bay, British Columbia, Canada, 1990–2020. The dataset included 2269 counts of Marbled Murrelets per transect per day, over 31 years and 19 transects.

Fixed Effects

Variable	Estimate	Standard error	*Z* score	*P* value
Intercept	0.012	0.207	0.057	0.954
Transect Width (100–400 m)	0.989	0.394	2.508	0.012
Distance to Louise Island	−1.034	0.135	−7.632	2.31×10^{-14}
Day of Year (DOY)	0.264	0.044	6.025	1.69×10^{-9}
Quadratic Day of Year (DOY^2)	−0.220	0.041	−5.373	7.73×10^{-8}
Year	−0.190	0.169	−1.123	0.261

Random Effects

Variable	Variance	Standard deviation
Transect Identifier	0.292	0.541
Year	0.352	0.593

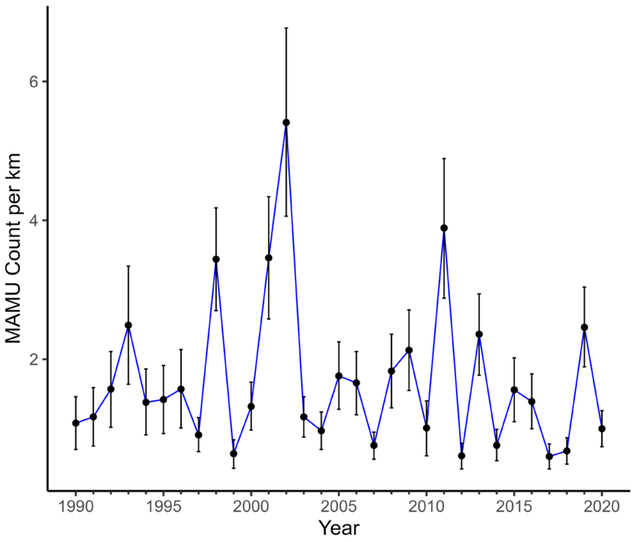


Fig. 3. Predicted Marbled Murrelet *Brachyramphus marmoratus* counts (birds/km) for each year, with confidence intervals (± standard error) showing annual variability. Mean annual counts were derived from a mixed-effects model, considering variability related to day of year, distance to shore, and transect width. Here, transect width is assumed to be 100 m for all years.

the transect to Louise Island, the nearest large land mass (Fig. 4A). Seasonally, counts increased early in the survey season, peaked around mid-June, and declined slightly towards the end of the survey season (i.e., July; Fig. 4B). These patterns were the same for data from both the wider transects and narrower transects, indicating that both survey protocols were effective in capturing these trends.

Environmental predictors of Marbled Murrelet counts

To explore the large fluctuations in Marbled Murrelet counts, we developed GLMMs that included environmental indicators of broad-scale oceanographic conditions (MEI, PDO) and proxies for localized prey availability (SST, Chl *a*). These models did not suggest that any of these factors were significant predictors of Marbled Murrelet counts in Laskeek Bay. As a visual comparison, we plotted the oceanographic conditions and indices alongside the predicted annual Marbled Murrelet counts. We found that, although peak counts in 1998 corresponded to a strong El Niño (high SST, MEI, and PDO), other larger peaks that did not correspond to peaks in indices also occurred (e.g., 2002 and 2011; Fig. 5).

DISCUSSION

We analyzed trends in at-sea counts of Marbled Murrelets that spanned a 31-year period, the longest-running annual count of its kind in BC. After accounting for an important change in transect width in 1997, our findings suggested a non-significant decline of −1.55% per year, which is lower than results obtained by previous analyses of this time-series dataset (up to 2009) that did not account for this change in methodology (Burger *et al.* 2007, COSEWIC 2012). Hence, we cannot confirm a significant change in the Marbled Murrelet population in Laskeek Bay.

To explore the power of our trend model, we conducted a post-hoc analysis to evaluate the magnitude of the trend that could be detected as significant at the conventional alpha value of 0.05. We found that, due to the spatial and annual fluctuations seen in this dataset, our data would detect only a statistically significant decline of more than −2.1% per year, or a 68.2% decline over the whole 31-year study period. Previous trend calculations using this dataset

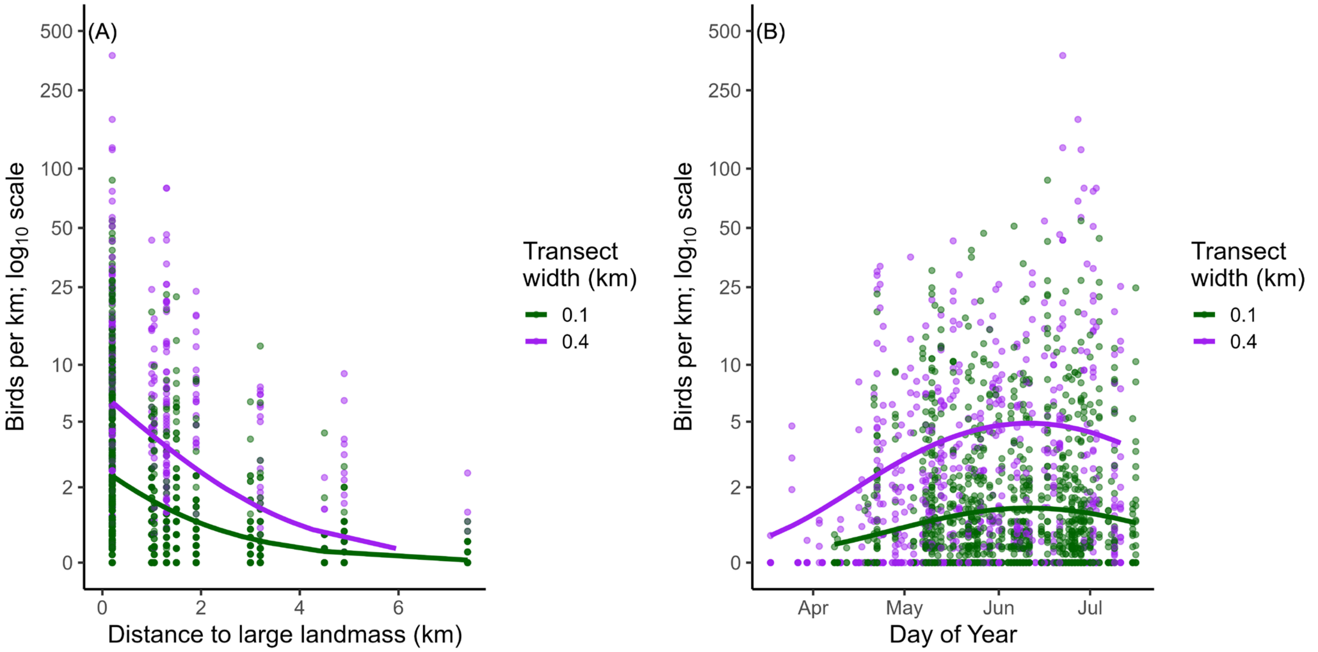


Fig. 4. Marbled Murrelet *Brachyramphus marmoratus* counts and trends over (A) varying distances from the nearest large landmass (Louise Island, British Columbia, Canada) and (B) throughout the survey season. For straight-line transects, distance from shore was measured from the middle of the transect line to Louise Island; for transects following the shoreline, the distance from shore is 200 m. Lines indicate the mean predicted counts from a mixed-effects model, which were calculated across the range of distances or dates while holding other variables at their median values.

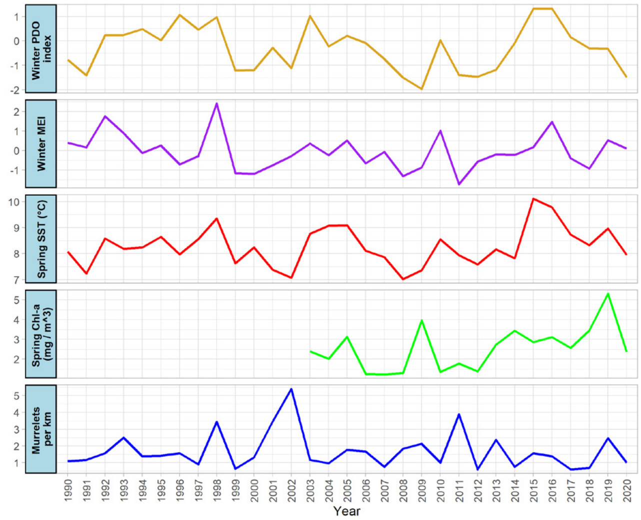


Fig. 5. Annual values of Pacific Decadal Oscillation (PDO), Multivariate ENSO Index (MEI), sea-surface temperature (SST), and chlorophyll *a* (Chl *a*) were used to explain variation in Marbled Murrelet *Brachyramphus marmoratus* counts in Laskeek Bay, British Columbia, Canada (counts shown on bottom panel for comparison). For PDO and MEI, negative values indicate a cooler phase (i.e., cooler-than-average water along the Pacific coast of North America) and positive values indicate warmer conditions (i.e., warmer-than-average water along the Pacific Coast of North America). Winter was defined as January to April, and spring was April to May.

showed steep declines, up to −14.6% per year (Burger *et al.* 2007) and, most recently, −11.3% per year (COSEWIC 2012). It is now evident that the negative trends were largely driven by high counts during the period from 1990 to 1996, when transects were 400 m wide, compared to 1997 and later, when transects were 100 m wide. We estimate that approximately 2.7 times fewer birds per kilometre would be observed with the narrower transects. The difference between the change in width (−75%) and the change in numbers counted (−63%) suggests that a proportion of birds were missed using the wider transects. Using formal distance sampling, Ronconi & Burger (2009) found that there was a high probability of observing a murrelet within 80 m of the survey boat. Hence, it is likely that current LBCS methods (transect width of 50 m on either side of the boat) capture the majority of murrelets that would have been present in the survey catchment. Using distance-sampling methods might improve estimates (e.g., Raphael *et al.* 2007). However, it is unlikely that LBCS would be able to implement these techniques in the future, as distance sampling requires intensive training that would be difficult to supply to volunteer observers. Moreover, the typical observer height (eye-level about 1.5 m above the water) makes judging distances greater than 50 m progressively more difficult, which reduces the potential accuracy of distance sampling with our boat. However, our results demonstrate that our narrow-transect method is an effective alternative to distance sampling for our situation.

Compared to previously estimated trends for Marbled Murrelet numbers in Laskeek Bay, the absence of a strong trend in at-sea counts aligns better with radar counts in the Haida Gwaii conservation region. A recent examination of trends from radar counts revealed, for the first time, a slight decline. Radar counts of Marbled Murrelets from 2003 to 2018 revealed a significant population decline (−2.8% per year) for the entire Haida Gwaii conservation region (Drever *et al.* 2021). Trends from the three radar stations within 30 km of Laskeek Bay (Fig. 1) suggested a −1.5% per year decline at Windy Bay (on the outer east coast, similar to Laskeek Bay), a −0.4% per year decline at Lagoon Inlet (at the head of several inlets to the west of Laskeek Bay), and a 0.1% per year increase at Klunkwoi Bay (in an inlet to the southwest of Laskeek Bay), all non-significant. Two radar stations at Hutton Inlet and Long Inlet seemed to be driving the significant decline calculated for the entire Haida Gwaii conservation region with the radar monitoring program.

For comparison to previous analyses (Burger *et al.* 2007, COSEWIC 2012), we generated predictions of annual counts that were controlled for transect, distance to shore, and the time of year. Once these variables were controlled, dramatic peaks in numbers in some years were still apparent. Although some of these peaks coincide with particular oceanographic conditions, others do not; the models suggested no strong relationship between larger- or smaller-scale ocean conditions and Marbled Murrelet counts. During the period from 1990 to 2020, there were several years in which the BC coast experienced warmer-water El Niño conditions in spring (e.g., 1993, 1998, 2010 and 2016; Boldt *et al.* 2020, Strong & Duarte 2023), a variable that has been shown to affect some aspects of seabird biology in the area (Gaston & Smith 2001, Shoji *et al.* 2012). In Laskeek Bay, the strong El Niño events in 1993 and 1998 both coincided with peak Marbled Murrelet counts. However, with more recent data, the relationship with El Niño is not evident (e.g., there were relatively low counts during the 2010 and 2016 El Niño events), possibly due to changing oceanographic baseline conditions and marine heatwaves (Boldt *et al.* 2020).

Previous analysis based on the earliest data from Laskeek Bay found a relationship between peak counts in 1993 and a decline in murrelets numbers on the west coast of Vancouver Island, which is 400–600 km to the southeast of our study area (Burger 2002). Both Burger (2002) and Gaston (1996) suggest that movement between regions could be driving these large fluctuations and that in an oceanographically poor year (i.e., during an El Niño event), there could be a movement from the west coast of Vancouver Island to the east coast of Haida Gwaii. In addition, Bertram *et al.* (2015) suggested that inter-annual variation in radar counts due to ocean conditions may result from birds moving away from areas having poor prey availability (e.g., Ronconi & Burger 2008). Likewise, in the US state of Washington—a Marbled Murrelet population that is contiguous with the BC population—at-sea surveys noted higher murrelet counts in inshore regions during El Niño, suggesting that inshore areas might provide better habitat when ocean conditions on the outer coast are more stressful (Lorenz & Raphael 2018).

For over 30 consecutive years, Marbled Murrelets occurred in our study area at annual densities between 0.60 to 5.41 birds per kilometre, highlighting the importance of the local marine habitat. Laskeek Bay may act as a refuge, as witnessed by the large influxes of birds in six unusual years, including during some El Niño events (1993 and 1998). Laskeek Bay supports Pacific Sand Lance *Ammodytes hexapterus* habitat (Pastran 2020), a favoured prey of Marbled Murrelets, and the bay attracts many other breeding and foraging alcids (LBCS unpubl. data, Pattison *et al.* 2017). In addition to bird influxes from elsewhere, it is plausible that years with high Marbled Murrelet counts on the water could indicate poor breeding years when fewer birds attempted to breed (or more birds failed to breed) and therefore spent more time on the water (Falxa

& Raphael 2016). This relationship is hard to tease apart due to the challenges associated with monitoring reproductive success for Marbled Murrelets.

At-sea counts showed a recent influx of birds in 2019. However, it is unlikely the visiting birds came north from the west coast of Vancouver Island because at-sea counts from that region also showed a peak in 2019 (Zharikov & Yakimishyn 2020). However, it is plausible that birds from Alaska could have moved south to Laskeek Bay. Marbled Murrelets from BC can travel up to 2900 km north to the US state of Alaska during the summer (Bertram *et al.* 2016, Bertram *et al.* 2023). Both Haida Gwaii and Alaska are in the Alaska Current ecosystem, while Vancouver Island is in the California Current System (Weingartner *et al.* 2009). Colonial nesting seabirds, including other alcids, fare differently in these two ecosystems (Bertram *et al.* 2017), with those in northern BC apparently having more stable or increasing populations while those in the California Current System are declining in population (Gaston *et al.* 2009). Marbled Murrelets, a non-colonial seabird, appear to deviate from this trend and have been found to be increasing in the California Current south of BC (McIver *et al.* 2021).

The Laskeek Bay Marbled Murrelet dataset is the only long-term one from the north coast of BC, making it an important reference point for comparison to other regions. An important next step for analyses of Marbled Murrelet at-sea survey datasets will be to broaden the scope and scale of analyses, to look for relationships between fluctuations in numbers throughout the species' range in Canada and the USA (see preliminary example analysis in Fig. A1). A range-wide analysis would facilitate the detection of large-scale movements within and between regions. To investigate patterns and determine the causes of large-scale movements, researchers would require coordinated analysis of at-sea surveys coupled with tracking studies throughout the species' range. As satellite tags become smaller and more accurate, the opportunity for range-wide tracking of Marbled Murrelets will improve. Then, movement data could be combined with regional demography using integrated models (e.g., Kissling *et al.* 2023) to gain a mechanistic understanding of local and regional trends.

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