COMPARING COUNTS MADE FROM DRONE-BASED AND BOAT-BASED PHOTOGRAPHY FOR SURVEYING THICK-BILLED MURRE *URIA LOMVIA* CLIFF COLONIES

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ABSTRACT

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Surveys of cliff-nesting seabirds from sea level or ground level often miss individuals hidden by topography, leading to underestimates of abundance. Thick-billed Murres *Uria lomvia* are especially challenging to survey accurately due to their dense nesting on vertical cliff ledges in remote northern regions. In Canada, updated colony surveys are needed, as currently used population estimates, done from boats, are outdated. Drones offer better vantage points and may reduce availability bias (i.e., the proportion of birds present but not visible), but direct comparisons with boat-based counts are essential. We compared murre counts from drone- and boat-based photographs of six vertical cliff sections at East Digges Island, Nunavut. Each section spanned from sea level to ~100 m, and over 50,000 murres were manually counted. On average, drone images detected 14% more murres than boat images, with differences ranging from 4% to 21%. The disparity was greater in upper cliff areas (10%–28%) than lower ones (2%–17%), where visibility from sea level is better. In one extreme case, the drone-based count was 101% higher than the boat count for the same area. We conclude that drone imagery improves detectability, especially at higher cliff elevations, and provides more reliable colony size estimates. These findings have direct relevance for assessing historical estimates and planning future surveys. Drone-based monitoring should be prioritized where feasible, and where boat-based imagery is used, correction factors based on cliff structure may improve colony estimates. More accurate estimates will enhance the management and conservation of Thick-billed Murres in Canada, particularly when informing harvest regulations.

Key words: seabirds, survey, monitoring, management, drones

INTRODUCTION

Accurate censusing of seabird cliff colonies presents substantial logistical and methodological challenges, yet it is vital for understanding population trends, guiding conservation action, and monitoring ecosystem health. In general, cliff-nesting seabirds' conspicuous breeding habits and tendency to concentrate in large colonies make them relatively accessible for population monitoring, but their breeding locations—often on remote, steep, and exposed cliffs—pose considerable obstacles to comprehensive surveys. Moreover, uncertainty in seabird counts and subsequent estimates of colony size is introduced from the observation process itself including availability bias (the proportion of birds present that are detectable) and count error (the proportion of detectable birds that are detected), as well as biological processes such as colony composition (the proportion of birds present that are breeding) and colony attendance (the proportion of breeders present). The observation process is especially influential to colony size estimates when surveys are conducted from suboptimal vantage points, such as boats or aircraft (Bibby et al., 2000). Despite these challenges, long-term monitoring programs continue to yield critical insights into the effects of climate change, fisheries pressure, and pollution on seabird population variation (Brisson-Curadeau et al., 2017; Burger & Gochfeld, 2004; Cury et al., 2011; Edney & Wood, 2021; Einoder, 2009; Piatt et al., 2007).

In Canada, monitoring Thick-billed Murres *Uria lomvia* is particularly complex due to the species' preference for nesting in densely packed colonies on vertical cliffs in remote Arctic and sub-Arctic environments (Birkhead & Nettleship, 1980; Gaston et al., 2012; Tuck, 1960). Thick-billed Murres breed in immense aggregations, often numbering in the hundreds of thousands, in locations that are difficult to access from either land or sea. These logistical challenges, combined with the visual complexity of counting birds packed tightly on sheer cliffs with often deep ledges, make murres especially prone to miscounts due to birds being hidden from view and imprecise correction factors being applied to incomplete data. Although global populations remain substantial, significant regional declines have been documented, particularly in breeding areas such as Greenland, Iceland, and Svalbard (Descamps et al., 2013, 2025; Frederiksen et al., 2021; Merkel et al., 2014, 2016). The status of Canadian populations is of growing concern, given ongoing harvest in Newfoundland and Labrador and the potential impacts of fisheries bycatch (Cox et al., 2024; Gaston et al., 1993). Traditional survey methods such as ground-based or boat-based photography are subject to detection biases linked to limited visibility and constrained vantage points. For example, Gaston et al. (1985) acknowledged the difficulty of boat-based counts at Digges Sound in Nunavut, where visibility was so limited that they applied a twofold correction factor to compensate—an approach that may have unintentionally overestimated true abundance due to the inherent uncertainty in applying uniform multipliers across heterogeneous cliff sections. Other attempts to address detection error, such as the use of cliff-top counts, plot-based extrapolations, or double-observer protocols (Birkhead & Nettleship, 1980; Hatch & Hatch, 1989), have likewise struggled to fully resolve the challenges posed by complex terrain and hidden portions of colonies.

Unmanned aerial vehicles (UAVs), or drones, offer a promising new solution to the detectability and accessibility constraints of traditional seabird survey methods. In recent years, the use of drones in wildlife monitoring has increased rapidly, including for seabirds (Brisson-Curadeau et al., 2025; Christie et al., 2016; Edney et al., 2023; Nowak et al., 2018). Drones equipped with high-resolution cameras can safely access remote, steep, or otherwise inaccessible nesting sites, capturing oblique and nadir images that enhance detectability and allow for the archiving of permanent, verifiable records (Edney & Wood, 2021). Multiple studies have demonstrated that drone surveys cause minimal disturbance to seabirds when conducted with appropriate protocols (Brisson-Curadeau et al., 2017; Lyons et al., 2019). The maneuverability of drones and their ability to photograph at varied angles is particularly advantageous for cliff-nesting species, helping to reduce availability bias from traditional sea-level or ground-based vantage points. However, to fully leverage this technology, comparisons must be made between drone-derived data and historical datasets collected using other methods to ensure consistency in long-term population assessments. We expected that drone-based imagery would inevitably increase detectability of cliff-nesting murres compared with boat-based imagery taken from sea level. Our objective here was to quantify the disparity, as well as the variation in that disparity, such that detectability correction factors for counts made from boat-based imagery could be developed. We expected the disparity to be greater at higher cliffs due to the effects of further reduced visibility from sea level of birds on ledges. We also explored the influence of drone angle on the disparity in counts between drone-based and boat-based imagery, expecting that more downward-facing oblique angles would result in higher visibility of murres on ledges and hence higher counts made from drones. Ultimately, our goal was to address differences in availability bias between these two photographic survey methods such that historical and future surveys made by boat could be adjusted to better capture true colony size.

METHODS

Digges Sound is home to the largest or second-largest (numbers at Akpatok Island in Ungava Bay are poorly known but may be higher) aggregation of breeding Thick-billed Murres in Canada. It is located around the northern tip of the Ungava Peninsula, at the junction of Hudson Strait and Hudson Bay (Fig. 1). Murres nest on the northeastern side of Digges Sound, with colonies on the southeastern side of East Digges Island, Nunavut, and directly across the sound, on the mainland of Quebec, in an area often referred to as Cape Wolstenholme—in reality, just south of that landmark (Fig. 1). On East Digges Island, the colony extends along an unbroken 4-km stretch of cliff that averages around 150 m high, ranging to nearly 200 m (Gaston et al., 1985).

We conducted a photographic survey at the East Digges Island colony on 09 July 2024. All methods were approved through the McGill Animal Use Protocol (2015-7599), a Canadian Wildlife Service permit (permit number: SC-NR-2022-NU-007), the Wildlife Research permit issued by the Department of Environment of the Government of Nunavut (permit number: 2024-011), and the Nunavik Marine Region Wildlife Board Resolution #2024-06-08. All methods were performed in accordance with the Canadian Council of Animal Care norms and Transport Canada regulations.

Boat photography was captured using a handheld Canon 7D Mark II with Series 100–400 mm lens set to 100 mm with a 1.6 times magnification for an effective lens dimension of 160 mm. The boat was driven at approximately 200 m from the base of cliffs,

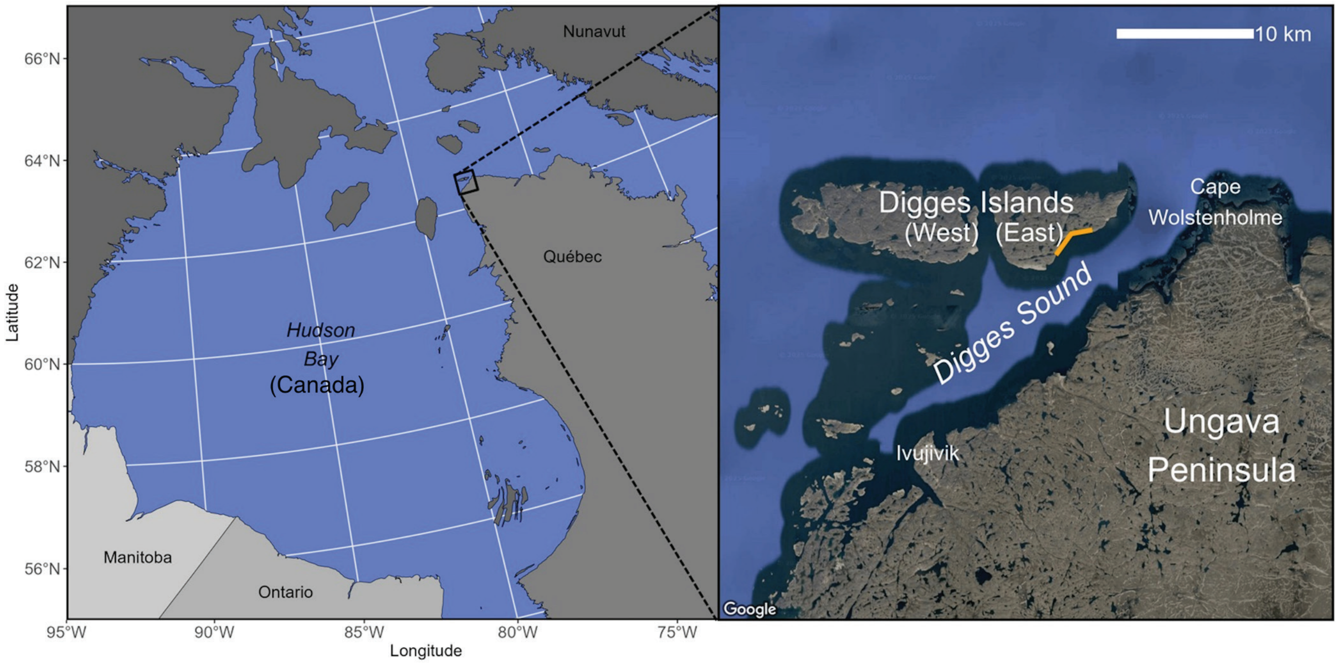

Fig. 1. Location of the study area in Canada. The study colony of Thick-billed Murre *Uria lomvia* on East Digges Island is indicated in orange.

as measured by GPS. Drone photography was captured using a Mavic 2 drone, with drone angle recorded in the metadata. The drone was flown at a constant distance of 50 m away from the colony to minimize disturbance. This distance was measured from the observer to the drone, and the drone pilot attempted to maintain that distance throughout all images by judging the relative size of murres. The drone was flown in vertical transects, moving from the top of the cliffs to the bottom, moving laterally to slightly overlap the previous vertical transect, and then flying to the top of the cliffs, with overlapping photos taken throughout each transect. We attempted to take photographs horizontally but would manipulate the camera angle where it was more beneficial to photograph from a different angle, such as where there were broad ledges. Images were taken simultaneously from the boat using both the handheld camera and drone beginning at 15h15, and all image capture was completed within one hour. Cliff areas covered by both drone and boat were located by finding matching landmarks. Fog was captured in some boat images, with areas completely obscured by fog restricted to the grassy tops of the cliffs where murres do not nest. Images were subsequently cropped to cover the same areas and joined in Microsoft PowerPoint (Version 16.67) to create a continuous strip of cliff from top to bottom (Fig. 2). This approach for stitching images was simple but allowed for the individual images to remain discrete, such that the drone angle could be considered. In total, six separate strips were identified and processed. The strips taken from the boat are made up of four individual images joined together from top to bottom, whereas the strips taken from the drone only required two to three images to be joined to cover the same area (Fig. 2).

The area covered by the top drone image of each strip was considered the upper "section" of the cliff, and the rest of the cliff was considered the lower section. This allowed consideration of the effect of cliff height on counts made from boat-based vs. drone-based imagery (Fig. 2). The location of the delineation

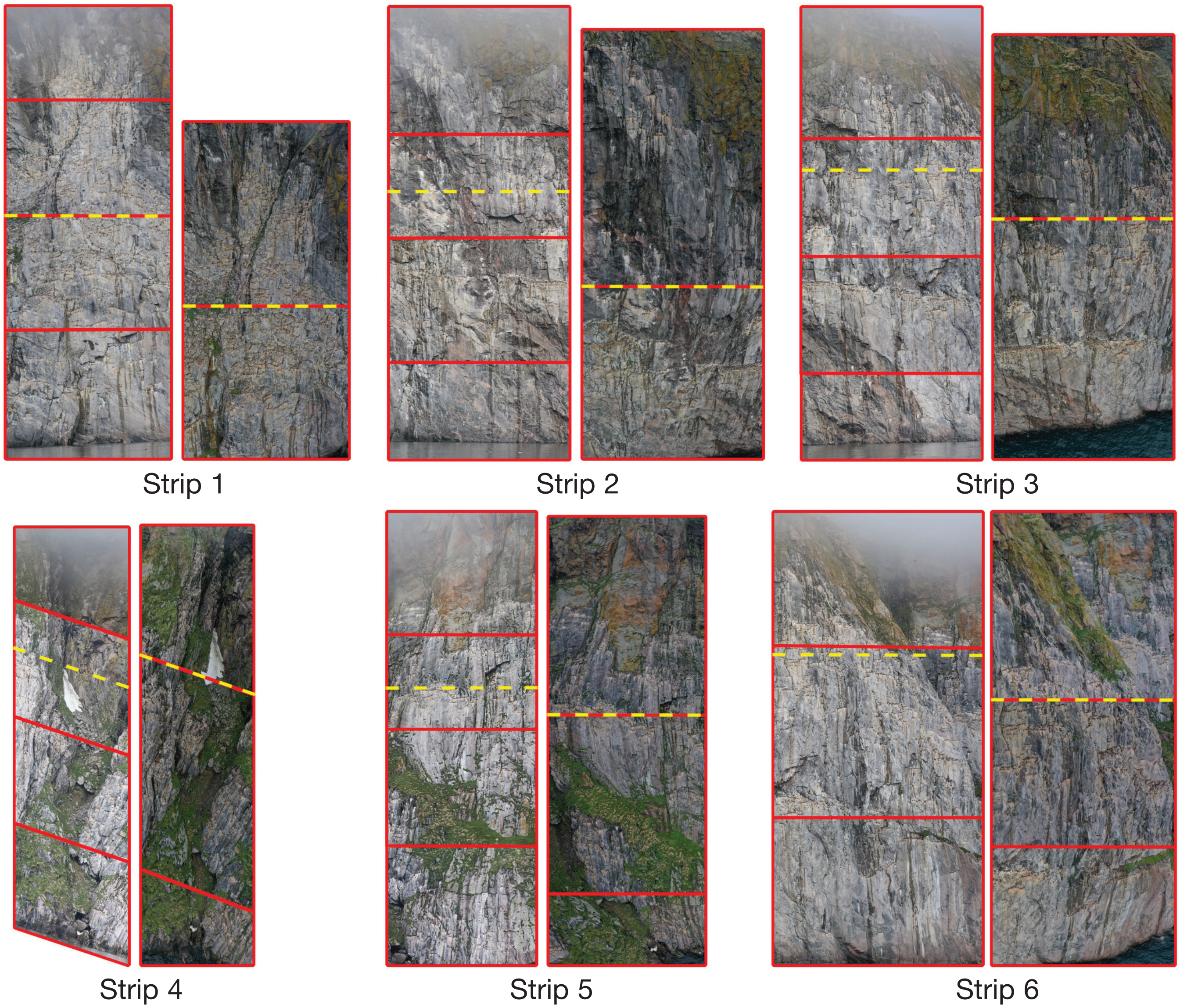

Fig. 2. Six paired imagery strips taken from a boat (left image of each pair) and by drone (right image of each pair). The red lines indicate individual images that were stitched together to create each strip, and the yellow dashed line indicates the delineation of the strips into upper and lower sections. Drone photos were taken by Douglas Noblet and boat photos were taken by Kyle Elliott on 09 July 2024 at East Digges Island, Nunavut, Canada.

between halves in the boat-based strips was based on identifying matching landmarks that were visible in both strips of the pair. Each strip was then cropped into eight smaller sub-images. Sub-images were uploaded to the online annotation platform CVAT.ai (CVAT.ai Corporation) to allow counting of individual murres by point annotation. Murres in flight, some constantly in flux, were not counted, as they may have flown in from other cliff sections. In addition to the six full strips of cliff considered, one additional pair of drone and boat images was annotated to provide a more extreme example of the potential variation in disparity in detectability between the two survey methods. Quality images were not available to create a complete cliff strip for each method, however we identified a pair of images capturing the same cliff area that included particularly wide occupied ledges and where the drone-based image had a particularly steep oblique drone angle of −59.10° (Fig. 3).

Volunteer annotators were recruited to assist in image annotation. The general annotation approach consisted of overlaying a grid over the image, carefully examining one grid cell at a time and placing a point annotation on individual murres. We erred on the side of positive detection when it was challenging to differentiate individual birds. We compared annotations made by the volunteers and the lead author on two training images (one boat-based and one drone-based); the total number of birds counted in the two images differed by < 1% for one volunteer. Thus, we proceeded with annotations by this one volunteer and the lead author, and we are confident that the two annotators were consistent in their annotations.

The annotations from each sub-image were exported from CVAT.ai and summed within survey methods at the level of sub-image, strip half, and strip and across all strips. Disparity between survey methods was then quantified between boat and drone counts at each level as the percentage difference between drone and boat counts (100 × [drone count − boat count]/boat count). We performed a logit transformation on the percent differences and completed the following analyses using the transformed data. To test whether percent differences were systematically higher in the upper cliff sections, we used a paired *t*-test. We then fit two linear models to investigate whether drone angle and cliff section (upper or lower) predicted the percent difference in counts. The first model included section and drone angle as predictors. The second model additionally included strip ID as a fixed effect to account for variation among cliff areas. We chose to include this second model to avoid attributing strip-specific variables to cliff height or drone angle and over-interpreting the results of the first model. All analyses were conducted using RStudio (Version 2024.4.2.764).

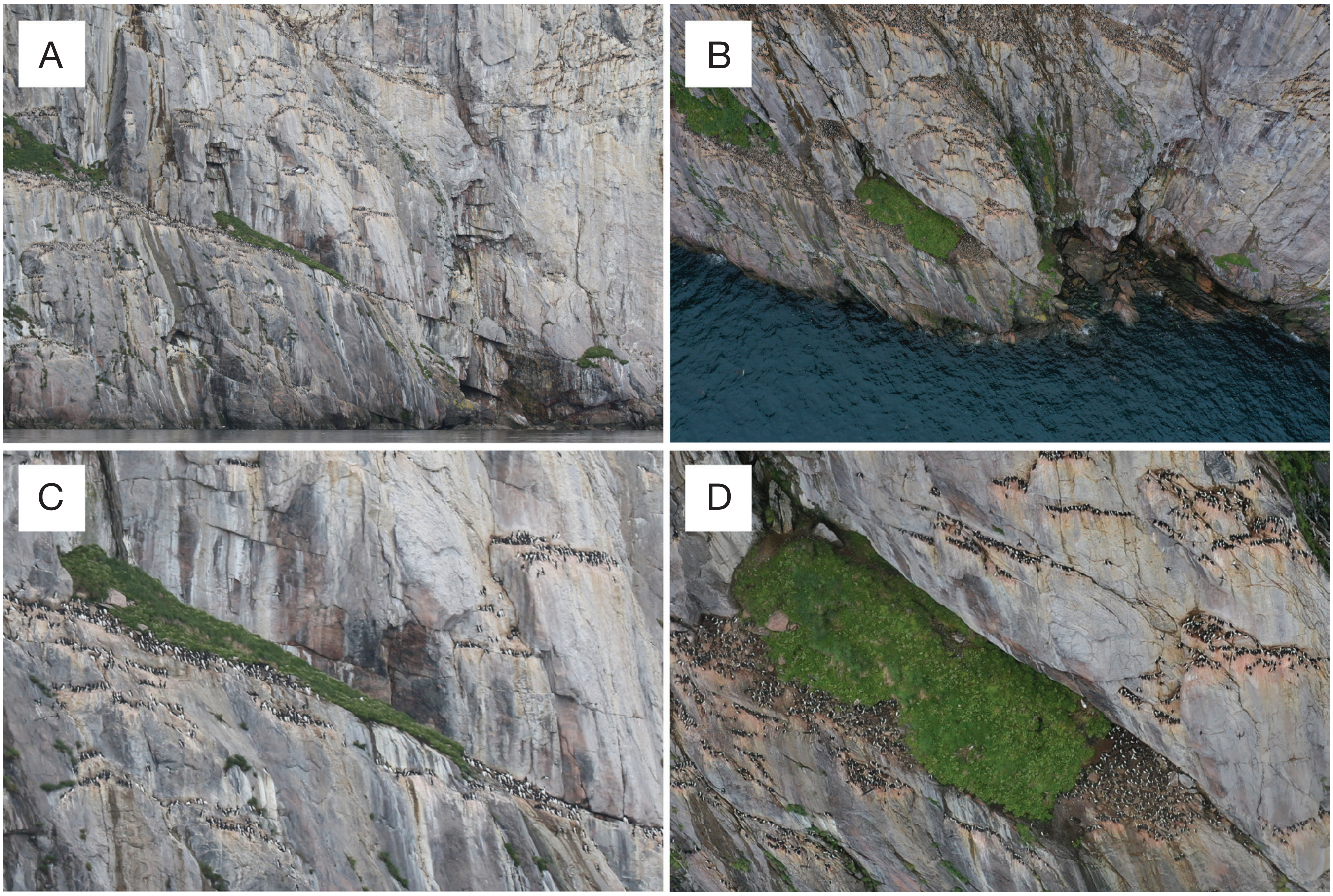

Fig. 3. Additional example imagery capturing the same area of cliff photographed from (A) a boat at sea level and from (B) a drone with a sharp downward oblique angle. Images in (C) and (D) are cropped versions of (A) and (B) to illustrate the disparity in detectability of Thick-billed Murres *Uria lomvia* on a deep occupied ledge. Drone photos were taken by Douglas Noblet and boat photos were taken by Kyle Elliott on 09 July 2024 at East Digges Island, Nunavut, Canada.

RESULTS

We counted 29,868 murres in the six strips of images taken by drone, whereas we counted 25,933 in the six strips of images covering the same areas taken from a boat. Thus, the drone point of view resulted in 14.1% more murres being detectable in images overall. Among individual strips, the difference between total counts made from drone and boat ranged from 4.1% to 20.6% (Fig. 4). The percent difference between drone and boat counts was consistently higher in the upper section of the cliff than in the lower section (mean ± standard deviation [SD]: upper cliffs, 20.3% ± 7.7 (range: 10.4%–28.4%); lower cliffs, 8.8% ± 5.0 (range: 2.2%–17.4%); paired $t(5) = 5.42$, $P = .003$; Fig. 4). The disparity between the upper and lower sections did not differ from a normal distribution based on a Shapiro-Wilk test ($W = 0.88$, $P = .26$). Overall, this indicates that drone-based counts diverged more from boat-based counts in images capturing the upper section of the cliff.

Drone angles varied among strips and also cliff sections, ranging from downward facing angles of −15° to −46° in the lower sections, and ranging between downward facing angles of −15° and upward facing angles of 11° in the upper sections. When accounting for differences between individual survey strips, a general linear model with survey strip as a fixed effect explained a larger proportion of the variation in percent difference (adjusted $R^2 = 0.7$) compared to a simple linear model excluding strip identity (adjusted $R^2 = 0.4$). In the survey-strip-as-a-fixed-effect model, neither section (upper vs. lower) nor drone angle showed clear effects on the percent difference ($P > .5$), indicating that strip-specific factors explain much of the variation in percent difference, overshadowing the effects of cliff height and drone angle. The simpler model, excluding strip identity, also showed no clear effect of drone angle ($P = .33$) and a weak effect of cliff section ($P = .037$), suggesting that cliff height is more important than drone angle in influencing discrepancies between counts made by drone versus boat. The additional pair of drone and boat images illustrate further the influence of drone angle on the variation in the disparity between counts made using the two survey methods, where the drone-based count was 101% higher than the boat-based count (Fig. 3).

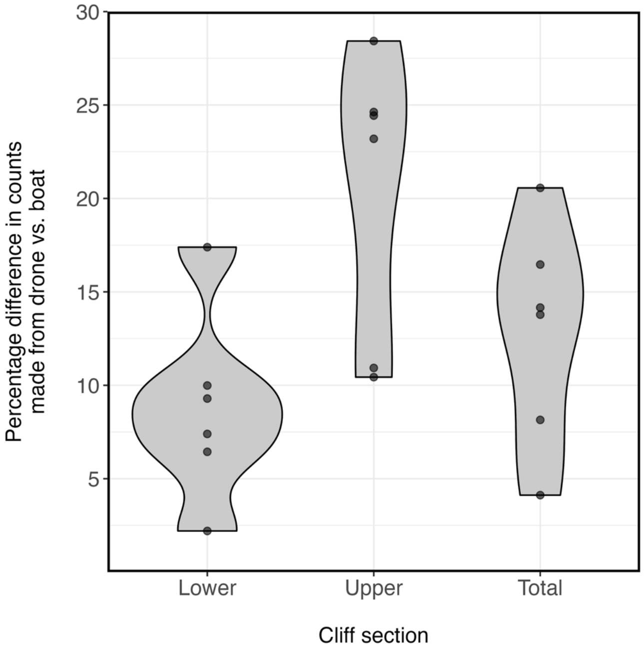

Fig. 4. Violin plots showing the percentage difference in counts of cliff-nesting Thick-billed Murres *Uria lomvia* made from vertical strips of drone-derived images versus vertical strips of boat-derived images from East Digges Island, Nunavut, Canada. Differences are shown for the upper and lower sections of each strip as well as the total of all images in each strip. Each point depicts a pair of drone–boat strips capturing the same vertical area of cliff. Wider sections of the violins represent a higher density of observations at that value range.

DISCUSSION

Our study confirms that drone-based photographic surveys reduce availability bias compared with traditional boat-based methods for estimating Thick-billed Murre abundance on cliffs. Drones provided improved vantage points, particularly in upper cliff sections where boat-based views were limited by the angle between the observer and the cliff and by obscuring ledges. Across all six vertical strips of images capturing sea level to cliff top, drone imagery revealed an average of 14% more murres than boat imagery, with differences exceeding 20% in upper cliff sections. These results support previous findings that drone surveys enhance seabird detectability and reduce bias in challenging environments (Brisson-Curadeau et al., 2017; Edney & Wood, 2021; Lyons et al., 2019). Further, while our models did not identify a strong statistical effect of drone angle when accounting for strip identity, we did find an example pair of images that confirmed that steep, downward-facing angles maximized murre detectability, particularly where ledges obscured birds. These patterns highlight the importance of optimal drone positioning in reducing availability bias, consistent with findings in other seabird drone studies (Brisson-Curadeau et al., 2025; Edney et al., 2023).

Our results also highlight the limitations of correction factors previously applied to boat-based surveys. Gaston et al. (1985) conducted the first thorough and systematic survey of the East Digges Island colony integrating boat-based photographs with top-of-cliff ground counts to derive a detectability correction factor of 2.4 (±0.19 standard error [SE]), later simplified to 2 with a range of 1.5 to 2.4. However, the majority of ground-based reference areas were at the tops of cliffs—precisely where boat visibility is most compromised. Our study provides empirical support for this concern: our most extreme case showed a 101% increase in murres detected in drone images compared to matching boat images, a value strikingly similar to Gaston's correction factor. Yet the disparity varied among strips from 4% to 21%, indicating that applying a correction factor range of 50% to 140% across a colony may introduce substantial miscounts. More refined, section-specific adjustments based on cliff height and structure—or better yet, drone surveys—are strongly recommended.

While drones present significant advantages, they are not without limitations. Cliff colonies in remote Arctic environments are often subject to high winds and sudden weather changes, which can impair drone flight, reduce image stability, or lead to equipment loss (Brisson-Curadeau et al., 2025; Edney et al., 2023). Experienced pilots are essential for operating in these conditions, and the cost of high-quality drones and training remains a barrier to widespread adoption. Furthermore, logistical constraints may prevent complete colony coverage in a single flight session. Drone disturbance is also a concern, which we addressed by collecting imagery at distances

> 50 m, beyond the 30-m threshold known to elicit flushing in murres (Brisson-Curadeau et al., 2017, 2025). Despite this, drone images consistently yielded higher counts, suggesting minimal disturbance. If flushing occurred, our drone counts are conservative. In sum, drones represent a powerful tool for improving seabird monitoring in remote cliff environments, provided their operational challenges are carefully managed and protocols standardized. Importantly, many people remain opposed to the use of drones to monitor wildlife due to the perception of potential disturbance (whether or not "scientifically" demonstrated; Markowitz et al., 2017) and as local community members have occasionally expressed for this project. At the same time, drones (as opposed to, for example, helicopters) could provide opportunities for northern communities to complete future counts independent of southern resources and therefore lead the monitoring of seabirds in many regions of the Arctic (Jackman et al., 2023; Young et al., 2022).

Environmental conditions are likely to be the main limitation to the use of drones in the Arctic. The small rotary drone we used cannot fly in winds above 30 km/h or rain; we were unable to complete the entire survey due to rain and wind at the end of the survey. Larger drones may require more advanced piloting and larger lithium batteries that are difficult to transport on airlines, and they may be noisier or more visible, impacting murre behaviour. In the moderate winds we were able to work within, the drone battery needed to be replaced every 20–30 min, which also limited our ability to complete the survey due to time lost replacing the batteries and because we had only four batteries available and no access to recharging in the field. Future survey teams should bring many extra batteries and a recharging station and plan for lengthy stays to have a window of suitable weather. Fixed wing drones, which are less impacted by wind, may also be an interesting possibility for future surveys, although the lack of stability may compromise photograph resolution.

Our findings have immediate application for ongoing monitoring at East Digges Island and similar colonies in Canada. Although we did not achieve full drone coverage in 2024, the colony was fully photographed from a boat. Based on our results, we recommend applying a provisional correction factor of 1.19 to boat-based murre counts, ideally stratified by cliff height and topography. Future drone surveys should prioritize comprehensive coverage and steep oblique imaging. Akpatok Island, which has the highest number of murres in Canada based on historical but possibly inaccurate counts, might be a particularly strong candidate for drone surveys, given its high cliffs and dense murre concentrations. As drone-based monitoring expands, careful attention must be paid when comparing results to historical boat-based surveys. Differences in murre counts among years may reflect improved detectability rather than true population change. Methodological consistency and correction for availability bias will be crucial for robust long-term population assessments. Similar studies should be conducted in future years and at different colonies. This could result in obtaining a more reliable correction factor or perhaps show the need for site-specific correction factors. It would also be worthwhile to examine whether the difference between drone and boat counts differs at the same locations in different years as the colony composition changes.

It is worth noting that recent advances in deep learning–based object detection offer potential to automate the processing of aerial imagery for cliff-nesting seabirds, including automated detection and colony size estimation. Ongoing work using helicopter survey imagery at Northern Fulmar *Fulmarus glacialis* colonies in Nunavut has shown that object detection models can achieve high accuracy in complex cliff environments. This is true, however, only after substantial investment in model development and training data, requiring tens of thousands of high-quality annotations even for a visually distinct species (S. Gutowsky, personal communication, February 4, 2026). Extending such approaches to murres presents additional challenges, as individuals are densely packed, often partially occluded, and difficult to distinguish from surrounding birds and background features. Manual annotation, therefore, remains necessary at present to ensure accurate and defensible counts, although efforts are underway to develop automated approaches, particularly for drone-based imagery. In this context, the annotations generated in this study contribute directly to the training data needed to advance such models.

Together, our results provide practical guidance for refining seabird monitoring at cliff colonies. Drone surveys offer a means to substantially reduce availability bias, improve count precision, and reconcile historical datasets with contemporary methods. Incorporating drones into seabird monitoring programs—while acknowledging their logistical limitations—offers a clear path toward more accurate, repeatable, and scalable assessments of population status for this and other species of conservation concern.

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AUTHOR CONTRIBUTIONS

EM: Writing—original draft, visualization, methodology, investigation, formal analysis, data curation. SEG: Writing—original draft, writing—review & editing, visualization, validation, methodology, investigation, conceptualization, supervision. KHE: Writing—original draft, writing—review & editing, validation, methodology, investigation, conceptualization, project administration, funding acquisition, supervision.

REFERENCES

Bibby, C. J., Burgess, N. D., Hill, D. A., & Mustoe, S. (2000). *Bird census techniques* (2nd ed.). Academic Press.

Birkhead, T. R., & Nettleship, D. N. (1980). *Census methods for murres,* Uria *species: A unified approach* (Occasional Paper No. 43). Canadian Wildlife Service.

Brisson-Curadeau, É., Bird, D., Burke, C., Fifield, D. A., Pace, P., Sherley, R. B., & Elliott, K. H. (2017). Seabird species vary in behavioural response to drone census. *Scientific Reports*, *7*(1), Article 17884. https://doi.org/10.1038/s41598-017-18202-3

Brisson-Curadeau, É., Lacombe, R., Gousy-Leblanc, M., Poirier, V., Jackson, L., Petalas, C., Miranda, E., Eby, A., Baak, J., Léandri-Breton, D.-J., Choy, E., Legros, J., Tranze-Drabinia, E., & Elliott, K. H. (2025). A meta-analysis of the impact of drones on birds. *Frontiers in Ecology and the Environment*, *23*(2), Article e2809. https://doi.org/10.1002/fee.2809

Burger, J., & Gochfeld, M. (2004). Marine birds as sentinels of environmental pollution. *EcoHealth*, *1*, 263–274. https://doi.org/10.1007/s10393-004-0096-4

Christie, K. S., Gilbert, S. L., Brown, C. L., Hatfield, M., & Hanson, L. (2016). Unmanned aircraft systems in wildlife research: Current and future applications of a transformative technology. *Frontiers in Ecology and the Environment*, *14*(5), 241–251. https://doi.org/10.1002/fee.1281

Cox, A. R., Roy, C., Hanson, A., & Robertson, G. J. (2024). Canadian murre harvest management in the face of uncertainty: A potential biological removal approach. *The Journal of Wildlife Management*, *88*(4), Article e22573. https://doi.org/10.1002/jwmg.22573

Cury, P. M., Boyd, I. L., Bonhommeau, S., Anker-Nilssen, T., Crawford, R. J. M., Furness, R. W., Mills, J. A., Murphy, E. J., Österblom, H., Paleczny, M., Piatt, J. F., Roux, J.-P., Shannon, L., & Sydeman, W. J. (2011). Global seabird response to forage fish depletion—One-third for the birds. *Science*, *334*(6063), 1703–1706. https://doi.org/10.1126/science.1212928

Descamps, S., Merkel, B., & Strøm, H. (2025). Local variations in population trends and migration strategies of Brünnich's guillemots on Svalbard. *Marine Ecology Progress Series*, *765*, 101–114. https://doi.org/10.3354/meps14893

Descamps, S., Strøm, H., & Steen, H. (2013). Decline of an arctic top predator: Synchrony in colony size fluctuations, risk of extinction and the subpolar gyre. *Oecologia*, *173*(4), 1271–1282. https://doi.org/10.1007/s00442-013-2701-0

Edney, A. J., Hart, T., Jessop, M. J., Banks, A., Clarke, L. E., Cugnière, L., Elliott, K. H., Juarez Martinez, I., Kilcoyne, A., Murphy, M., Nager, R. G., Ratcliffe, N., Thompson, D. L., Ward, R. M., & Wood, M. J. (2023). Best practices for using drones in seabird monitoring and research. *Marine Ornithology*, *51*(2), 265–280. http://doi.org/10.5038/2074-1235.51.2.1544

Edney, A. J., & Wood, M. J. (2021). Applications of digital imaging and analysis in seabird monitoring and research. *Ibis*, *163*(2), 317–337. https://doi.org/10.1111/ibi.12871

Einoder, L. D. (2009). A review of the use of seabirds as indicators in fisheries and ecosystem management. *Fisheries Research*, *95*(1), 6–13. https://doi.org/10.1016/j.fishres.2008.09.024

Frederiksen, M., Descamps, S., Elliott, K. H., Gaston, A. J., Huffeldt, N. P., Kolbeinsson, Y., Linnebjerg, J. F., Lorentzen, E., Merkel, F. R., Strøm, H., & Thórarinsson, T. L. (2021). Spatial variation in vital rates and population growth of thick-billed murres in the Atlantic Arctic. *Marine Ecology Progress Series*, *672*, 1–13. https://doi.org/10.3354/meps13823

Gaston, A. J., Cairns, D. K., Elliot, R. D., & Noble, D. G. (1985). *A natural history of Digges Sound* (Report Series No. 46). Canadian Wildlife Service.

Gaston, A. J., de Forest, L. N., Gilchrist, G., & Nettleship, D. N. (1993). *Monitoring Thick-billed Murre populations at colonies in northern Hudson Bay, 1972–92* (Occasional Paper No. 80). Canadian Wildlife Service.

Gaston, A. J., Mallory, M. L., & Gilchrist, H. G. (2012). Populations and trends of Canadian Arctic seabirds. *Polar Biology*, *35*, 1221–1232. https://doi.org/10.1007/s00300-012-1168-5

Hatch, S. A., & Hatch, M. A. (1989). Attendance patterns of murres at breeding sites: Implications for monitoring. *The Journal of Wildlife Management*, *53*(2), 483–493. https://doi.org/10.2307/3801154

Jackman, A., Millner, N., Cunliffe, A. M., Laumonier, Y., Lunstrum, E., Paneque-Gálvez, J., & Wich, S. A. (2023). Protecting people and wildlife from the potential harms of drone use in biodiversity conservation: Interdisciplinary dialogues. *Global Social Challenges Journal*, *2*(1), 68–83. https://doi.org/10.1332/IMLH5791

Lyons, M. B., Brandis, K. J., Murray, N. J., Wilshire, J. H., McCann, J. A., Kingsford, R. T., & Callaghan, C. T. (2019). Monitoring large and complex wildlife aggregations with drones. *Methods in Ecology and Evolution*, *10*(7), 1024–1035. https://doi.org/10.1111/2041-210X.13194

Markowitz, E. M., Nisbet, M. C., Danylchuk, A. J., & Engelbourg, S. I. (2017). What's that buzzing noise? Public opinion on the use of drones for conservation science. *BioScience*, *67*(4), 382–385. https://doi.org/10.1093/biosci/bix003

Merkel, F., Boertmann, D., Falk, K., Frederiksen, M., Johansen, K., Labansen, A. L., Linnebjerg, J. F., Mosbech, A., & Sonne, C. (2016). Why is the last Thick-billed Murre *Uria lomvia* colony in central West Greenland heading for extinction? *Bird Conservation International*, *26*(2), 177-191. https://doi.org/10.1017/S0959270915000040

Merkel, F., Labansen, A. L., Boertmann, D., Mosbech, A., Egevang, C., Falk, K., Linnebjerg, J. F., Frederiksen, M., & Kampp, K. (2014). Declining trends in the majority of Greenland's thick-billed murre (*Uria lomvia*) colonies 1981–2011. *Polar Biology*, *37*(8), 1061–1071. https://doi.org/10.1007/s00300-014-1500-3

Nowak, M. M., Dziób, K., & Bogawski, P. (2018). Unmanned aerial vehicles (UAVs) in environmental biology: A review. *European Journal of Ecology*, *4*(2), 56–74. https://doi.org/10.2478/eje-2018-0012

Piatt, J. F., Sydeman, W. J., & Wiese, F. (2007). Introduction: A modern role for seabirds as indicators. *Marine Ecology Progress Series*, *352*, 199–204. https://doi.org/10.3354/meps07070

Tuck, L. M. (1960). *The murres: Their distribution, populations and biology* (Canadian Wildlife Series No. 1). Canadian Wildlife Service.

Young, B. G., Koski, W. R., Kilabuk, R., Watt, C. A., Ryan, K. P., & Ferguson, S. H. (2022). Collaborative field research using drones for whale photo-identification studies in Cumberland Sound, Nunavut. *Drone Systems and Applications*, *10*(1), 256–265. https://doi.org/10.1139/dsa-2021-0026