Using drone imagery to obtain population data of colony-nesting seabirds to support Canada's transition to the global Key Biodiversity Areas program

Lindsay A. R. Lalach, David W. Bradley, Douglas F. Bertram & Louise K. Blight

2023

Original citation:
Lalach, L.A.R., Bradley, D.W., Bertram, D.F., & Blight, L.K. (2023). Using drone imagery to obtain population data of colony-nesting seabirds to support Canada's transition to the global Key Biodiversity Areas program. *Nature Conservation*, *51*, 155–166. https://doi.org/10.3897/natureconservation.51.96366

Nature Conservation 51: 155–166 (2023)
doi: 10.3897/natureconservation.51.96366
https://natureconservation.pensoft.net

SHORT COMMUNICATION

A peer-reviewed open-access journal
Nature Conservation
Launched to accelerate biodiversity conservation

Using drone imagery to obtain population data of colony-nesting seabirds to support Canada's transition to the global Key Biodiversity Areas program

Lindsay A. R. Lalach[1], David W. Bradley[1], Douglas F. Bertram[2], Louise K. Blight[3,4]

1 *Birds Canada, Delta, BC, V4K 2T9, Canada* **2** *Institute of Ocean Sciences, Environment Canada Wildlife Research Division, 9860 West Saanich Rd, P.O. Box 6000, Sidney, BC, V8L 4B2, Canada* **3** *School of Environmental Studies, University of Victoria, Victoria, British Columbia V8P 5C2, Canada* **4** *Procellaria Research & Consulting, Salt Spring Island, British Columbia V8K 1G2, Canada*

Corresponding author: Lindsay A. R. Lalach (lindsay.lalach@gmail.com)

Academic editor: F. Bonet | Received 24 October 2022 | Accepted 31 January 2023 | Published 15 February 2023

https://zoobank.org/BC583166-866E-4A41-B201-3195E6E3958F

Citation: Lalach LAR, Bradley DW, Bertram DF, Blight LK (2023) Using drone imagery to obtain population data of colony-nesting seabirds to support Canada's transition to the global Key Biodiversity Areas program. Nature Conservation 51: 155–166. https://doi.org/10.3897/natureconservation.51.96366

Abstract
Identifying of global or national biodiversity 'hotspots' has proven important for focusing and prioritizing conservation efforts worldwide. Canada has nearly 600 Important Bird and Biodiversity Areas (IBAs) identified by quantitative criteria to help guide avian conservation and management. Marine IBAs capture critical waterbird habitats such as nesting colonies, foraging sites, and staging areas. However, due to their remote locations, many lack recent population counts. Canada has begun transitioning IBAs into the global Key Biodiversity Areas (KBA) program; KBAs identify areas that are important for the persistence of biodiversity and encompass a wider scope of unique, rare, or vulnerable taxa. Assessing whether IBAs qualify as KBAs requires current data – as will future efforts to manage these biologically important sites. We conducted a pilot study in the Chain Islets and Great Chain Island IBA, in British Columbia, to assess the effectiveness of using drones to census surface-nesting seabirds in an IBA context. This IBA was originally designated for supporting a globally significant breeding colony of Glaucous-winged Gulls (*Larus glaucescens*). Total nest counts derived from orthomosaic imagery (1012 nesting pairs) show that this site now falls below the Global and National IBA designation criterion threshold, a finding consistent with regional declines in the species. Our trial successfully demonstrates a flexible and low cost approach to obtaining population data at an ecologically sensitive KBA site. We explore how drones will be a useful tool to assess and monitor species and habitats within remote, data-deficient IBAs, particularly during the transition to KBAs.

Keywords
conservation, Important Bird and Biodiversity Areas (IBAs), population data

Introduction

Important Bird and Biodiversity Areas (IBAs) are sites that contain a recurring presence of one or more regionally or globally threatened species (BirdLife International 2010). These sites are designated using standardized selection criteria that apply numerical thresholds (e.g., occupied by a minimum % of a global breeding population) to determine the significance of a site for conservation; these thresholds are applied consistently to sites around the world. IBAs are continually recognized for their influence and significant use for conservation policies in multilateral environmental agreements, site protection and land-use planning, and for their involvement in driving locally-led stewardship programs (Wren and Couturier 2009; Waliczky et al. 2018).

The International Union for Conservation of Nature (IUCN) developed a process to identify Key Biodiversity Areas (KBAs) that was released in 2016; this conservation tool aims to identify sites that are important for the persistence of biodiversity and encompasses all taxa, as well as ecosystems in the assessment process. The criteria and thresholds for assessments of KBAs builds on the approach of the IBA program and other conservation framework tools, while bringing in other criteria based on vulnerability and irreplaceability (IUCN 2016). Species-specific KBA assessments require population data collected through field surveying and monitoring, and a gap analysis of the KBA program has identified the need for updated survey data to ensure sites originally designated as IBAs still meet their respective thresholds under KBA criteria (Langhammer et al. 2007). Although systematic and effective field-based protocols have been developed for monitoring IBAs (BirdLife International 2006), limitations to conducting surveys such as accessibility leaves some sites with a lack of updated and accurate data. Among these are remote or otherwise difficult to access marine sites worldwide.

As the world's second-largest nation (9.98 million square kilometres), Canada lacks the biodiversity of smaller tropical countries, but has many areas of critical importance for aspects of temperate biodiversity. There are currently 581 sites identified as IBAs throughout the country. Approximately 64% of these IBAs are considered data deficient (Evans 2022), meaning they cannot currently be established as KBAs due to the lack of consistent and reliable data for the given 'trigger' species (i.e., the species meeting KBA criteria at a given site) . A significant number of these IBAs border Canada's coastlines and are designated for seabird breeding colonies, foraging areas, or coastal stopover sites for migratory shorebirds (Wren and Couturier 2009).

As with other nations, a high proportion (approximately 75%) of Canadian data deficient IBA sites are coastal and marine. Monitoring seabird colonies through field surveying is often expensive, difficult, and dangerous, and will invariably cause disturbance to nesting birds (Burger 1997). Thus, new approaches to data gathering should be considered in order to obtain information sufficient to retain such remote and important sites if they do meet the quantitative criteria for KBA designation. Remotely Piloted Aircraft Systems (RPAS), or drones, are increasingly being used for ecological research in areas that are difficult or dangerous to access (Watts et al. 2008). The use of drones to survey seabird colonies provides an opportunity to access sites that are otherwise challenging or hazardous to access directly. Compared to ground-based survey methods, RPAS can also allow for increased spatial coverage and frequency of surveying, reduced risk of entering remote island locations, and increased accuracy of counts (McClelland et al. 2016; Hodgson et al. 2018). Additionally, RPAS can be of a similar cost to or less expensive than ground-based surveys, and, as capabilities are improved, costs will likely continue to decrease.

In this study, we used RPAS technology to estimate an IBA population count of a colonial-nesting seabird, the Glaucous-winged Gull (*Larus glaucescens*). Our objectives were to support the IBA program's evolution to a KBA-based initiative; to explore the overall feasibility of using drone-based applications to obtain reliable IBA or KBA data; and to assess the current status of a nationally important seabird colony. This study location has historically supported one of Pacific Canada's largest breeding colonies of Glaucous-winged Gulls, as well as migratory aggregations of as many as 2000 Brandt's Cormorants (*Urile penicillatus*) in the area. For this reason, it was categorised as an A4i IBA and D1 KBA site, one which is "known or thought to hold 1% or more of a biogeographic population of a congregatory waterbird species on a regular basis" (Moore and Couturier 2011). We wanted to use our counts to help determine if the area still meets the threshold that it was originally assessed for when it was designated an IBA 25 years ago, prior to the steep decline observed in this gull species beginning in the 1980s (Blight et al. 2015).

Methods

Study Site

Our study took place at the Chain Islets and Great Chain Island IBA, a cluster of small islets and rocky outcrops along the marine coastline south of the City of Victoria in the Strait of Juan de Fuca (48.42°N, 123.28°W), British Columbia (Fig. 1). This site also comprises the Oak Bay Islands Ecological Reserve. The IBA is 1.38 km^2 in size and consists of rocky flats and rocky shorelines with grass and sedge meadows, and sand flats throughout. The rocky islets within the IBA are sparsely vegetated, Great Chain Island is the largest and the most vegetated island with a herbaceous cover. Both Great Chain and the rocky islets are used by nesting and migrating seabirds. As this site lies within an introgression zone (Bell 1996), our references to Glaucous-winged Gulls include any Western Gull (*L. occidentalis*) × Glaucous-winged Gull hybrids.

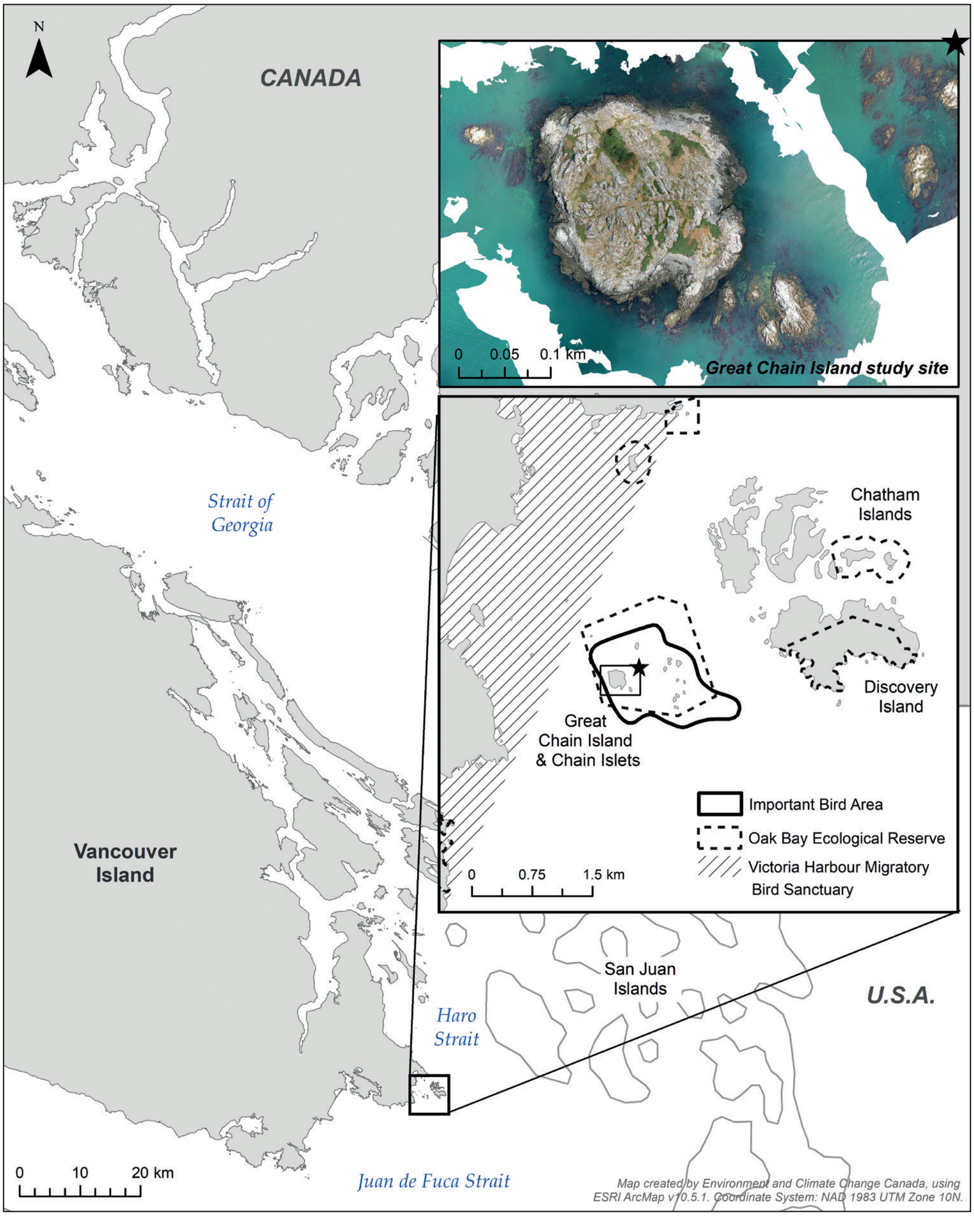

Figure 1. Great Chain Island & Chain Islets IBA, British Columbia, Canada. Environment and Climate Change Canada, 2022.

Flight/drone specifics

RPAS flight operations and protocol were selected to be consistent with a previous study in the region (Blight et al. 2019). Drone imagery for this study was collected using a multi-rotor RPAS (DJI Mavic 2 Pro) with a 20-megapixel Hasselblad L1D-20c aerial camera. Flights were performed on 21 June 2019 from 0859 to 1257 h, with operations run from the aft deck of a 42-foot former commercial fishing vessel. The survey date was chosen based on known local breeding phenology of Glaucous-winged Gulls and was meant to capture the maximum number of occupied nests, when breeding adults are likely either incubating eggs or brooding newly hatched chicks (Blight et al. 2014). Weather conditions on the day of the flight were clear skies with flat, calm water and minimal wind speed (~Beaufort 0–1).

Flights were pre-programmed through drone mapping software (DroneDeploy, www.dronedeploy.com) to run single straight-line paths across the colony, offset to achieve consistent sidelap and followed by a return to the stationary vessel. Due to strong tidal currents in the region, the vessel motored in place instead of dropping anchor, with all vessel operations occurring outside the Ecological Reserve boundary, approximately 650 metres from Great Chain Island; this distance was well beyond the 100 m launch distance recommended by Vas et al. (2015) for minimising effects on waterbird behaviour. The drone climbed vertically until survey altitudes were achieved and then flew horizontally over the colony. The altitude above ground level of the drone flights varied from 90–65 metres, with initial flights starting at 90 meters, a height at which we observed no disturbance in an earlier study in the region (Blight et al. 2019). Flight altitude was adjusted according to the natural topography of the islands and generally decreased for each subsequent flight after no Glaucous-winged Gull disturbance was observed.

Image capture was via a 28 mm lens on auto-exposure mode, certain flight specifics such as speed over ground and photo intervals were set by front-lap and side-lap requirements within the drone software. As flight altitudes and topography were variable throughout the six flights, ground sample distance (GSD) also varied. GSD ranged from 1.41 cm/pixel at 60 meters altitude to 2.11 cm/pixel at 90 meters. Drone flights were operated using one pilot and one visual observer, along with two additional observers monitoring the colony for any evidence of disturbance to nesting gulls during drone operations.

Data overview

We used photogrammetry software to process drone flight images and create orthomosaics of the study area. Clear weather on the day of the flight generally created optimal light conditions for subsequent visual assessment of the orthomosaic imagery. However, solar glare on the less-vegetated small islets (approx. 33% of the colony) rendered a subset of the images overexposed; these islets were excluded from subsequent analysis. Orthomosaics of Great Chain were enlarged and visually scrutinised on-screen for occupied gull nests; these were readily apparent as the white and pale grey plumage of an incubating gull contrasts strongly with its background of rock and vegetation, and its posture is distinctive (Fig. 2). Thus, we assumed that each incubating bird represents a nesting pair; as two mates may attend one nest, two birds sitting side by side in an incubation pose were counted as a single pair. The Glaucous-winged Gulls we

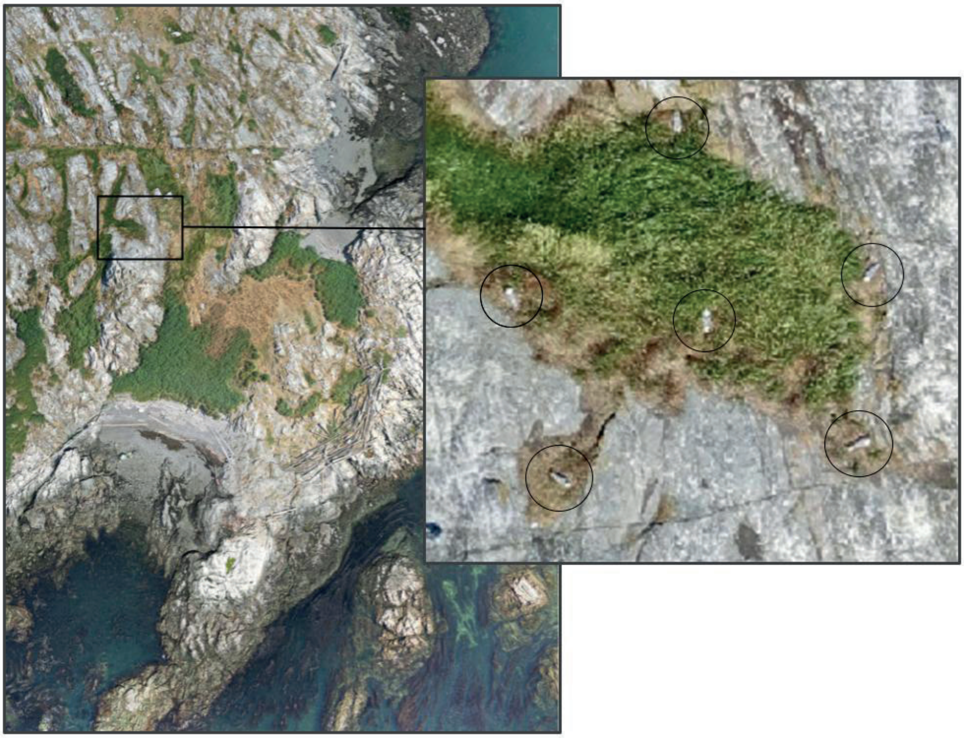

Figure 2. Gull nests detected within an enlarged portion of orthomosaic imagery.

identified were primarily on nests, birds flying overhead and apparently roosting along the shoreline were also visible but were not included in the total nest count. As each individual nest was counted, a pin was placed over it to eliminate duplicate counts. The orthomosaic encompassed Great Chain Island as well as several of the small islets situated within the IBA (Chain Islets; Fig. 1).

Results

We conducted six flights capturing the entire IBA in 537 raw images. In the orthomosaic of Great Chain Island (Fig. 1), 1012 active nests were counted in total. Imagery from the drone overflights was sufficient to census the breeding population of our target population over about 67% of its nesting colony. However, the smaller rocky islets proved difficult to survey, with little vegetation cover and a surface layer of white gull guano; they were subject to solar glare and resultant overexposed imagery. Survey data collected in 2009 indicated 464 nests within the small islets of the IBA (33% of the colony). Using these data, we then assessed the counts against the KBA criteria to determine if this site still reaches the specific thresholds to categorize it as a KBA.

At all flight altitudes, no reaction was observed from nesting gulls during drone overflights, with the only alarm-calling or flushing by gulls observed when a single Bald

Eagle (*Haliaeetus leucocephalus*), a gull predator, flew low over the colony on one occasion. No other seabird species were detected through the imagery analysis. The only other vertebrate species observed remotely on land was Harbour Seal (*Phoca vitulina*).

Discussion

Our study successfully demonstrated an approach to using RPAS to survey and evaluate the population status of a colonial seabird at an ecologically sensitive and difficult-to-access site, in the context of monitoring an existing Important Bird and Biodiversity Area. The area overflown during the flights is natural, open rocky topography which generally creates an ideal setting for this type of analysis. The imagery captured from the flights was sufficient to analyze the large island within the IBA, however, some of the smaller rocky islets with little vegetation proved difficult to assess due to the high sun glare off the rocks and therefore were excluded from this trial. However, we were able to make use of previous surveys to estimate the nest counts for this minor part of the colony. Our project budget did not extend to extensive post-processing work, but we suggest that under similar conditions it might be possible to adjust exposure on each image prior to stitching the orthomosaic together to allow for a clearer visual of overexposed tiles. Alternatively, for rocky seabird colonies on light-coloured and/or guano-coated rocky substrate, drone surveys might best be scheduled for overcast days. The smaller islets within the IBA were not counted during this study, however with the addition of a 33% count of 464 nests (928 individuals), the total population of 1476 nests (2952 individuals) still would not qualify the site under the existing KBA thresholds.

KBA assessment and population trends

Our count results were similar to ground-based survey data collected a decade earlier (Blight et al. 2015) as well as more recent estimates by Ecological Reserve wardens (J. Sirois and M. Lambert, pers. comm). Our drone-based count confirms that the breeding population now falls below the KBA threshold to designate this site, a finding consistent with regional declines in the species (Blight et al. 2015). The estimated total of 2952 individuals accounts for approximately 67% of the threshold needed to classify this site as a KBA. Currently, to reach a national threshold for Glaucous-winged Gull, an aggregation representing 1% or greater of the national population size over a season, and during one or more life history stages is required, resulting in a threshold of 4,400 individuals. Globally, the same requirements are necessary, resulting in a threshold of 4,700. While this specific site no longer qualifies for KBA status, there is potential to extend the boundaries of this site to create a larger KBA with the inclusion of a similar sized colony nearby, Mandarte Island. These two sites, combined with Mitlenach Island in the northern Strait of Georgia, account for a quarter of the breeding gulls in British Columbia (Booth 2001). In Pacific Canada, there are 10 other IBA sites with Glaucous-winged Gull as the trigger species that could be candidates for future RPAS analysis.

Canada is one of the first countries globally to transition IBAs to the KBA program. Two main challenges identified in the program crosswalk relating to survey data are data age and repeatability (Birds Canada, pers. comm.). "Lack of population data" was listed as a key methodological issue in six out of seven regions in an early assessment of KBA progress globally (Foster et al. 2012) and it remains a challenge in the development of the program. While drones and other remote technologies are not a panacea for this problem – particularly where lack of funding is a key issue – expanding the type of approaches available is important for some data-deficient sites, as demonstrated by this study. Recent literature explores the potential use of semi-automated counts on drone imagery of breeding waterbirds through free software and highlights the effectiveness and accessibility of this method as a low-cost alternative to manual counts for conservation use (Francis et al. 2020; Corregidor-Castro and Valle 2022). The cost of this survey was comparable to the 2-day field operation required to undertake this census as a ground-based survey. This semi-automated method can be especially cost-effective for areas such as IBAs that need accurate repeat surveys and for large areas that are difficult to access (Francis et al. 2020).

Drone applications

Though the use of RPAS technology has rapidly increased, gaps remain in establishing best practices for surveying sensitive species (Vas et al. 2015) and literature on methods and guidelines for this approach continues to evolve (Vas et al. 2015; Rush et al. 2018; Weimerskirch et al. 2018; Francis et al. 2020). The technique utilized in this study caused no evident disturbance to nesting birds, as was anticipated based on previous work in the region (Blight et al. 2019). However, our study's IBA is located less than 2 km from the City of Victoria and birds may be habituated to air traffic due to their proximity to the Victoria aerodrome. Though Glaucous-winged Gulls are considered a non-sensitive species in this context, lack of disturbance is an important survey factor for colonial bird studies, especially during sensitive life cycle stages including breeding. Geldart et al. (2022) studied the heart-rate response of drone surveys on colonial-nesting Eider ducks (*Somateria mollissima*), in Nunavut, Canada; their results indicated no physiological stress response from drones flying 30 m above the nesting colony. However, the authors highlight that other species may perceive a greater threat to drones, specifically avian species that may experience adult predation from other avian predators (Geldart et al. 2022). This study, among others, allows researchers to better understand the behavioural and physiological response of birds to drones and highlights that, when done properly and in accordance with available guidelines to avoid disturbance to seabird and waterbird colonies, RPAS can allow for a less invasive surveying method that provides adequate coverage of a site in significantly less time compared to land-based surveys.

Drone surveying can not only assist in the establishment of KBAs but can provide critical population and habitat monitoring which can indicate habitat loss or degradation. It is evident that climate change will continue to pose stressors that may lead to fluctuations in biodiversity, potentially impacting elements for which a conservation site was initially designated (KBA Canada Coalition 2021). Bollard et al. (2022) explore drone technology for mapping protected areas in Antarctica to provide baseline vegetation inventories and ecological data for future monitoring. This method proved useful in obtaining vegetation maps that show spatial cover with higher accuracy and resolution, though small intricate taxa such as lichen and cyanobacteria could not be accurately monitored through this method (Bollard et al. 2022). The low impact of this survey method at a sensitive site, combined with its repeatability and inexpensiveness, made this a successful demonstration of collecting baseline data for a protected area.

While our study only used RPAS to obtain a viable count of breeding gulls, the imagery could be used to indicate the area of occupancy, the extent of suitable habitat, and the range of such habitat for this and other species; these are all metrics that are considered acceptable to assess qualifying KBA sites (KBA Canada Coalition 2021). Further, such metrics can be monitored over time to indicate future changes to habitat and ecosystems. The drone imagery was high-resolution enough and the visibility on our survey day clear enough for us to view the extent of the underwater kelp (*Nereocystis luetkeana*) forests surrounding the archipelago, as well as macroalgae in the intertidal zone (cf. Cavanaugh et al. 2021; Tait et al. 2021), indicating the utility of drone imagery for assessing multiple species and habitats at a target site. This methodology could prove useful for assessing a range of species across various landscapes to support the KBA assessment process.

Conclusion

Obtaining updated population data is critical to understanding change and detecting risks to biodiversity. Drones provide the opportunity to significantly advance our understanding of environmental changes, especially within remote environments. The results of this study add to growing literature showing the effective use of drones in surveying surface-nesting birds in natural, hard-to-access settings. In a rapidly changing world where biodiversity continues to decline, obtaining accurate inventory data to capture that change remains a logistical challenge for many IBAs (Donald et al. 2018). Adapting to such rapid change with new technologies can allow for systematic monitoring and updated data for both wildlife and ecological communities as KBAs and protected areas are established and continue to evolve.

Acknowledgements

We would like to thank Alexandra King for creation of the map figure, Environment and Climate Change Canada Wildlife Research Division and Canadian Wildlife Service for funding the drone surveys, as well as Captain Bruce Evans and Fishing Vessel

Misty Lady and visual observer Brian Badesso. We would also like to thank Geoff Mullins as the drone pilot for this survey and InDro Robotics for UAV-related support.

The authors have declared that no competing interests exist.

References

Bell DA (1996) Genetic differentiation, geographic variation and hybridization in gulls of the *Larus glaucescens-occidentalis* complex. The Condor 98(3): 527–546. https://doi.org/10.2307/1369566

BirdLife International (2006) Monitoring Important Bird Areas: a global framework. BirdLife International. Version 1.2. Cambridge.

BirdLife International (2010) Marine Important Bird Areas toolkit: standardised techniques for identifying priority sites for the conservation of seabirds at-sea. BirdLife International, Version 1.1., Cambridge.

Blight LK (2014) Glaucous-winged gull (*Larus glaucescens*) colony count data, Georgia Basin, BC, Canada, 1900–2010. Figshare. Dataset. https://doi.org/https://doi.org/10.6084/m9.figshare.1218437.v1

Blight LK, Marc DC, Arcese P (2015) A century of change in Glaucous-winged Gull (*Larus glaucescens*) populations in a dynamic coastal environment. The Condor 117(1): 108–120. https://doi.org/10.1650/CONDOR-14-113.1

Blight LK, Bertram DF, Kroc E (2019) Evaluating UAV-based techniques to census an urban-nesting gull population on Canada's Pacific coast. Journal of Unmanned Vehicle Systems 7(4): 312–324. https://doi.org/10.1139/juvs-2019-0005

Bollard B, Doshi A, Gilbert N, Poirot C, Gillman L (2022) Drone Technology for Monitoring Protected Areas in Remote and Fragile Environments. Drones 6(2): 1–42. https://doi.org/10.3390/drones6020042

Booth, BP (2001) Southern Vancouver Island Marine Waters and Seabird Islands Important Bird Areas Conservation Plan, 1–41. https://www.ibacanada.org/documents/conservationplans/bcsouthernvancouverisland.pdf

Brisson-Curadeau E, Bird D, Burke C, Fifield DA, Pace P, Sherley RB, Elliott KH (2017) Seabird species vary in behavioural response to drone census. Scientific Reports 7: e17884. https://doi.org/10.1038/s41598-017-18202-3

Burger A (1997) Inventory Methods for Seabirds: cormorants, gulls, murres, storm-petrels, ancient murrelet, auklets, puffins and pigeon guillemot. Province of British Columbia Resources Inventory Committee, 1–62. https://ecoreserves.bc.ca/wp-content/uploads/1997/03/Inventory-Methods-for-Seabirds-cormorants-gulls-murres-storm-petrels-Ancient-Murrelet-auklets-puffins-and-Pigeon-Guillemotseabml-web02.pdf

Cavanaugh K, Bell T, Hockridge E (2021) An automated method for mapping giant kelp canopy dynamics from UAV. Frontiers in Environmental Science 8: e587354. https://doi.org/10.3389/fenvs.2020.587354

Corregidor-Castro A, Valle RG (2022) Semi-automated counts on drone imagery of breeding seabirds using free accessible software. Ardea 110(1): 89–97. hhttps://doi.org/10.5253/arde.v110i1.a7

Donald P, Fishpool L, Ajagbe A, Bennun L, Bunting G, Burfield I, Butchart SHM, Capellan S, Crosby MJ, Dias MP, Diaz D, Evans M, Grimmett R, Heath M, Jones VR, Lascelles BG, Merriman JC, O'Brien M, Ramírez I, Waliczky Z, Wege DC (2018) Important Bird and Biodiversity Areas (IBAs): The development and characteristics of a global inventory of key sites for biodiversity. Bird Conservation International 29(2): 177–198. https://doi.org/10.1017/S0959270918000102

Evans D (2022) Crosswalk Results: Important Bird and Biodiversity Areas to Key Biodiversity Areas in Canada. http://kba-maps.deanrobertevans.ca/ [Accessed on 10.8.2022]

Foster MN, Brooks TM, Cuttelod A, De Silva N, Fishpool LDC, Radford EA, Woodley S (2012) The identification of sites of biodiversity conservation significance: Progress with the application of a global standard. Journal of Threatened Taxa 4(8): 2733–2744. https://doi.org/10.11609/JoTT.o3079.2733-44

Francis JR, Lyons BM, Kingsford RT, Brandis KJ (2020) Counting mixed breeding aggregations of animal species using drones: Lessons from waterbirds on semi-automation. Remote Sensing (Basel) 12(1185): e1185. https://doi.org/10.3390/rs12071185

Geldart EA, Barnas AF, Semeniuk CA, Gilchrist HG, Harris CM, Love OP (2022) A colonial-nesting seabird shows no heart-rate response to drone-based population surveys. Scientific Reports 12(1): e18804. https://doi.org/10.1038/s41598-022-22492-7

Hodgson J, Mott R, Baylis S, Pham T, Wotherspoon S, Kilpatrick A, Raja Segaran R, Reid I, Terauds A, Koh L (2018) Drones count wildlife more accurately and precisely than humans. Methods in Ecology and Evolution 9(5): 1160–1167. https://doi.org/10.1111/2041-210X.12974

IUCN (2016) A Global Standard for the Identification of Key Biodiversity Areas, Version 1.0. First edition. IUCN, Gland, 1–46. https://portals.iucn.org/library/sites/library/files/documents/2016-048.pdf

KBA Canada Coalition (2021) A national standard for the identification of key biodiversity areas in Canada v. 1.0. Wildlife conservation society Canada and key biodiversity area Canada coalition, Toronto. https://doi.org/10.19121/2021.Report.39502

Langhammer PF, Bakarr MI, Bennun LA, Brooks TM, Clay RP, Darwall W, De Silva N, Edgar GJ, Eken G, Fishpool LDC, Da Fonseca G A B, Foster MN, Knox DH, Matiku P, Radford EA, Rodrigues ASL, Salaman P, Sechrest W, Tordoff AW (2007) Identification and Gap Analysis of Key Biodiversity Areas: Targets for Comprehensive Protected Area Systems. IUCN, Gland, 1–134. https://portals.iucn.org/library/efiles/documents/pag-015.pdf

Mcclelland GTW, Bond AL, Sardana A, Glass T (2016) Rapid population estimate of a surface-nesting seabird on a remote island using a low-cost unmanned aerial vehicle. Marine Ornithology 44: 215–220.

Moore J, Couturier A (2011) Canadian Important Bird Areas Criteria (2nd edn.), 1–7. https://www.ibacanada.ca/documents/current_Canadian_IBA_Criteria.pdf

Rush GP, Clarke LE, Stone M, Wood MJ (2018) Can drones count gulls? Minimal disturbance and semiautomated image processing with an unmanned aerial vehicle for colony-nesting seabirds. Ecology and Evolution 8(24): 12322-12334. https://doi.org/10.1002/ece3.4495

Tait L, Orchard S, Schiel DR (2021) Missing the forest and the trees: Utility, limits and caveats for drone imaging of coastal marine ecosystems. Remote Sensing 13(16): e3136. https://doi.org/10.3390/rs13163136

Vas E, Lescroël A, Duriez O, Boguszewski G, Grémillet D (2015) Approaching birds with drones: First experiments and ethical guidelines. Biology Letters 11(2): e20140754. https://doi.org/10.1098/rsbl.2014.0754

Waliczky Z, Fishpool L, Butchard S, Thomas D, Heath M, Hazin C, Allison T (2018) Important Bird and Biodiversity Areas (IBAs): Their impact on conservation policy, advocacy and action. Bird Conservation International 29(2): 199–215. https://doi.org/10.1017/S0959270918000175

Watts AC, Bowman WS, Abd-Elrahman AH, Moham-ed A, Wilkinson BE, Perry J, Kaddoura YO, Lee K (2008) Unmanned Aircraft Systems (UAS) for ecological research and natural-resource monitoring. Ecological Research 26(1): 13–14. https://doi.org/10.3368/er.26.1.13

Weimerskirch H, Prudor A, Schull Q (2017) Flights of drones over sub-Antarctic seabirds show species- and status-specific behavioural and physiological responses. Polar Biology 41: 259–266. https://doi.org/10.1007/s00300-017-2187-z

Wren LS, Couturier AR (2009) Canada. In: Devenish C, Díaz Fernández DF, Clay RP, Davidson I, Yépez Zabala I (Eds) Important Bird Areas Americas – Priority sites for biodiversity conservation. BirdLife Conservation Series No. 16, BirdLife International, Quito, Ecuador, 113–124. http://datazone.birdlife.org/userfiles/file/IBAs/AmCntryPDFs/Canada.pdf