MIXED METRICS AND THE NEED TO ADJUST REMOTE-SENSING DATA IN THE EVALUATION OF KEY BIODIVERSITY AREAS FOR COLONIAL-NESTING SEABIRDS: AN EXAMPLE WITH GLAUCOUS-WINGED GULLS *LARUS GLAUCESCENS*

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ABSTRACT

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Conservation initiatives such as the Key Biodiversity Areas (KBA) Programme use standardized criteria based on estimates of species abundance to identify critical habitats. They therefore depend on accurate estimates of population sizes for target species. It is essential that the metrics used to measure abundance at a candidate site are consistent with those used to estimate total abundance at national or global scales, because only then can it be determined whether abundance at a site meets threshold criteria. Imagery gathered by remotely piloted aircraft systems (RPAS, or drones) has rapidly become a tool for determining abundance of surface-nesting seabirds and, therefore, can assist with the designation of KBAs. However, abundance data derived from drone imagery are often in different units, such as numbers of birds or numbers of incubating adults visible on photographs, than data derived from in-person counts, which generally measure the number of nests or breeding pairs. Therefore, drone data may not be directly comparable to data that have been historically collected to estimate overall breeding-population sizes. This study considered a candidate colony of Glaucous-winged Gulls *Larus glaucescens* located in the Salish Sea in southwestern Canada, which has been surveyed both by drone and by traditional ground surveys. We developed a conversion factor that at least partially translates counts of incubating Glaucous-winged Gulls detected on drone imagery to an estimate of breeding pairs. Compensating for only nests without incubating adults, results suggest that numbers of incubating adults detected by drone likely represent between 63% and 84% of the total number of breeding pairs. Applying this conversion increased the population estimate for the colony and changed former conclusions about whether the site met recommended criteria for designation as a national or global KBA for Glaucous-winged Gulls.

Key words: survey methodology, remotely piloted aircraft systems, drones, conservation assessment, marine birds, population size

INTRODUCTION

The Key Biodiversity Areas (KBAs) Programme is an ambitious global initiative to identify sites that currently support significant components of biodiversity on planet Earth. A set of standards was developed in 2016 by the International Union for the Conservation of Nature (IUCN 2016) to provide a framework that could be used for identifying biological hotspots and designating them as KBAs. The standards include a variety of criteria that are relevant to different taxa, ecosystems, and distribution patterns. The program extends and subsumes previous efforts targeting specific taxa, such as the identification of Important Bird and Biodiversity Areas (IBAs; BirdLife International 2010, 2024), to include all forms of life. Cataloguing these bastions of biodiversity is intended to help focus conservation efforts and stem the flood of species and ecosystem extinctions that have been associated with rapid human population growth and concomitant unsustainable resource consumption by humans (Kolbert 2014).

The KBA Programme and other conservation initiatives use estimates of species abundance to identify critical habitats, and therefore depend on accurate population-size estimates for target species. For avian species in North America, the national, continental, or global population-size estimates most commonly used in these programs are from the Partners in Flight network (PIF 2021). Estimates from *Birds of the World* accounts (Billerman 2022) and from *Waterbird Population Estimates, 5th Edition* (Wetlands International 2023) are also used (M. Bradford pers. comm.). The accuracy of available population estimates varies, and most methods used to derive estimates incur potential biases and sources of error. For landbirds, PIF population estimates are based primarily on extrapolations of roadside data from the North American Breeding Bird Survey (BBS; Sauer *et al.* 2017). Analysing BBS data presents many statistical challenges. However, refined methodology addresses some concerns about the representativeness of the roadside sampling data, applies adjustment factors related to time of day and detectability, and explicitly incorporates uncertainty in the data. The results provide distributions of population-size estimates rather than point estimates (Stanton *et al.* 2019). For seabirds that nest in colonies, a variety of methods are used to estimate colony populations, including total nest counts, sample quadrats distributed randomly or systematically through nesting areas, counts from photographs, and estimates based on the extent of the colony or the numbers of birds present (Bibby *et al.* 2000). Most colony sites are known, and regional, national, or continental population estimates can be derived as sums of individual colony estimates within respective jurisdictions (e.g., Sowls *et al.* 1978, Speich & Wahl 1989, Rodway 1991). Population-size estimates for seabirds described in *Birds of the World* species accounts are often derived in this fashion. However, population data are poor or out of date for many colonies due to their remote and difficult-to-access locations, and current population sizes at larger geographic scales can often be only approximated.

Comparability of abundance estimates is critical in evaluating relative population sizes at locations being considered for conservation designations, and this is particularly true for KBAs. In applying standard criteria to evaluate KBA sites, it is important that site-specific abundance metrics are consistent with those that are used to estimate total abundance at national or global scales—only then is it possible to determine whether abundance at a site meets threshold criteria (percent of national or global population). Imagery gathered by remotely piloted aircraft systems (RPAS, or drones) has rapidly become a tool for determining the abundance of a species at a site (Watts *et al.* 2008, Chabot *et al.* 2015, Edney *et al.* 2023), and it can assist with the designation of KBAs (Lalach *et al.* 2023a). Imagery from drones can be interpreted (via manual inspection or through computer processing) to provide reliable counts of visible individuals, is cost-effective, and, if used appropriately, is non-intrusive (Chabot *et al.* 2015; McClelland *et al.* 2016; Blight *et al.* 2019; Corregidor-Castro *et al.* 2021, 2022). Drone surveys are thus particularly applicable for surface-nesting seabird species like gulls. However, abundance data derived from drone imagery are often in different units, such as numbers of birds (Corregidor-Castro *et al.* 2022) or numbers of incubating adults (Lalach *et al.* 2023a) visible on photographs. They may not be directly comparable to data that have been historically collected to estimate the overall sizes of breeding populations, which are generally measured in units of nests or breeding pairs. Conversion factors must be developed to allow the comparison of such data (Chabot *et al.* 2015, Corregidor-Castro *et al.* 2022).

Canada has been a leader in adopting and applying KBA standards (KBA Canada Coalition 2021). National criteria developed for use in Canada differ from the global criteria developed by the IUCN (2016). Such modifications by regional and national jurisdictions were anticipated and suggested by authors of the global standards (IUCN 2016). Criterion D1 concerning demographic aggregations readily applies to colonial-nesting seabird species:

> Sites qualifying as national KBAs under criterion D1 predictably hold a significant proportion of the national population size of a taxon during one or more life history stages or processes, and so contribute significantly to the national persistence of biodiversity at the taxon level. Site predictably holds an aggregation representing ≥ 1% of the national population size of a taxon, over a season, and during one or more key stages of its life cycle. A site is considered to "predictably" hold a taxon if the taxon is known to have occurred at the site in at least two thirds of the years for which adequate data are available for the relevant season (e.g., the breeding season in the case of a breeding aggregation); the total number of years considered should not be fewer than three.
>
> —KBA Canada Coalition (2021, p. 18)

Criterion D1 for qualification as a KBA at a global scale requires ≥ 1% of the global (rather than national) population of a taxon (IUCN 2016). These thresholds are similar to those previously used to establish IBAs under the congregator species category, which initially designated sites based on ≥ 1% of the biogeographical population of a species at global, continental, or national levels (Chaundy & Wilcox 2001). Revised IBA criteria considered thresholds only at global and continental levels (Moore & Couturier 2011). National KBA standards in Canada re-instate the ≥ 1% threshold for national populations (KBA Canada Coalition 2021). However, continental population sizes have been considered more relevant for species that cross continental boundaries, and they are being used to evaluate and designate national KBAs for most avian species in Canada (KBA Canada Coalition 2021, Lalach *et al.* 2023b, M. Bradford pers. comm.).

The objectives of the present study were: first, to consider potential biases in abundance data gathered by drone that would limit comparability to population-size estimates used to evaluate KBAs for surface-nesting seabirds; and second, to develop suitable conversion factors to address those biases. We considered an example colony of Glaucous-winged Gull *Larus glaucescens* in the province of British Columbia (BC), Canada, for which data from traditional total-count ground surveys (Rodway *et al.* 2024) could be compared to data from drone imagery (Lalach *et al.* 2023a). Specifically, we developed conversion factors to render the data collected through drone surveys of a KBA candidate colony of Glaucous-winged Gulls (Lalach *et al.* 2023a) comparable to historical data used to estimate total breeding populations of that species in Canada (Rodway *et al.* 2018, 2024). We then considered the implications of applying the conversion factors for the evaluation of that colony as a potential KBA. Although only a single example colony is considered in this study, similar conversion factors could be developed for other colonies with historical data sets. Generalized conversion factors applicable at regional scales could also be developed through consideration of larger-scale data sets. Conversion factors should generally be considered when comparing colony count data collected using any two different methods (e.g., boat-based vs. land-based counts), but here, we focus on comparisons of historical (land-based) colony count data with aerial survey data collected via drone.

METHODS

Study site and species

The candidate colony used to evaluate biases in abundance data collected by drone was the island complex of Great Chain Island and the Chain Islets (hereafter, the Chain Group; see map in Lalach *et al.* 2023a) near Victoria, BC. This is a key breeding colony for Glaucous-winged Gulls in BC and one where surveys by traditional ground searches have been completed at various intervals over several decades. A recent study by Lalach *et al.* (2023a) measured the abundance of gulls nesting on this island complex using imagery gathered by drone. The site had previously been designated as an IBA in Canada (BirdLife International 2010) based on data from the 1980s (Vermeer & Devito 1989), and the purpose of the Lalach *et al.* (2023a) study was to re-evaluate the site to assist with the process of transitioning IBAs to KBAs. The unit of measurement used in the drone surveys was incubating adults visible on the photographs, each of which was assumed to represent one breeding pair.

The drone survey was conducted on 21 June 2019, when most birds present were likely incubating. The quality of the drone imagery was adequate to extract counts for Great Chain Island, which is partially vegetated, but not for the rest of the mostly rocky Chain Islets, as the camera's auto-exposure mode was unable to compensate for the strong reflected solar glare from guano-coated rock. Data from a previous, land-based survey of the rest of the Chain Islets conducted in 2009 (Blight 2012, 2014; Blight *et al.* 2015) were used in combination with the 2019 aerial count for Great Chain Island to evaluate whether the current size of that colony met the criteria for designation as a KBA. Conclusions of the study were that fewer gulls were nesting in 2019 than in the 1980s, and the site no longer met the criteria to qualify as a global or national KBA. However, that evaluation was problematic because the units of measurement used were not directly comparable to the units used to estimate national breeding populations, and no attempt was made to calibrate data from drone imagery to previous ground-survey estimates of population size on that colony. Also, the 2009 data for the Chain Islets (Blight 2014) that were used to augment the 2019 data included only nests with eggs, and so were not directly comparable to the ground-count data used to estimate national populations, which, for Glaucous-winged Gulls (and cormorant species), have consistently included all nests (Campbell *et al.* 1990, Rodway 1991, Rodway *et al.* 2018, 2024).

Determining whether populations nesting on the Chain Group colony meet the criteria for KBA designation requires comparison to estimates of national, continental, and global population sizes. Glaucous-winged Gulls nest along the Pacific coast of North America from Cape Romanzof, Alaska, USA, south to northwestern Oregon, USA, and in the Russian Far East on the Commander Islands and Kamchatka (Hayward & Verbeek 2020). The centre of their breeding population is in Alaska, where approximately 252 000 birds nest at 825 colonies (Denlinger 2006). In BC, a total of 47 860 individuals are estimated breeding at 344 colony sites as of 2023 (Rodway *et al*. 2024), a decrease of 14% from the previous estimate of about 55 500 breeding individuals as of 1990 (Rodway *et al.* 2018). (Colony sites are defined as distinct geographic sites that correspond, for the most part, to officially named islands or island clusters that support one or more nesting pairs; Rodway *et al.* 2024.) About 37 000 individuals were estimated to breed in the state of Washington, USA, in the 1980s (Speich & Wahl 1989). Partners in Flight estimated a global breeding population of 380 000 individuals in 2017 (PIF 2017), revised to 470 000 individuals in 2021 (PIF 2021). Using the revised 2021 estimates, KBA Canada (KBA Canada Coalition 2021) set continental and global thresholds at 4400 and 4700 individuals, respectively. Given the most recent estimates in Alaska and BC, we suspect that a more accurate estimate of current global breeding-population size is 380 000 individuals, with a North American population of about 350 000 individuals. Based on these estimates, current ≥ 1% threshold criteria for national, continental, and global KBAs for this species would be about 480, 3500, and 3800 breeding individuals, respectively, although, as noted above, KBA Canada currently uses continental thresholds for national criteria (Lalach *et al.* 2023b).

Breeding-population estimates for gulls have been derived following standardized survey protocols that, unless impractical, unsafe, or causing too much disturbance, involve counting all nests, including those lacking eggs or chicks, on each colony, with each nest considered to represent one breeding pair (Nettleship 1976, BCMELP 1997, Bibby *et al.* 2000, Rodway *et al.* 2024). Standard protocol dictates that a nest must at least have partially built-up sides to qualify (Nettleship 1976); a scrape with little or no accumulated nesting material is not counted as a nest unless it contains eggs, which sometimes occurs (Rodway *et al.* 2024). Including all empty nests may bias population estimates if breeding pairs build multiple nests, but greater biases can be introduced if empty nests are not included. There are many reasons for nests to be empty (see below), and it is not possible during surveys to determine whether nests are empty because they are duplicate nests built by one pair or because of some other reason. Proximity cannot be used to distinguish duplicate nests because nests of different pairs are sometimes located within a meter of each other (Vermeer 1963). Also, asking surveyors to judge whether an empty nest is a duplicate nest introduces subjective biases that compromise data comparability; including all empty nests in counts keeps data comparable across surveys. Regardless of possible biases, the important consideration for this study is that measures of abundance at a candidate colony need to be consistent with national and global breeding-population estimates that have been derived from total nest counts following standardized protocols.

There are two main biases in abundance data gathered from drone surveys of Great Chain Island. Both need to be considered before the derived population estimate can appropriately be compared to national or continental population-size estimates to determine whether Glaucous-winged Gull numbers on the island complex currently meet KBA criteria. Numbers of incubating adults counted by Lalach *et al.* (2023a) differ from numbers of breeding pairs by the omission of 1) nests without incubating adults; and, potentially, 2) nests with incubating adults that were not detectable in the drone imagery because they were obscured by vegetation. Developing a conversion factor for the first omission requires estimating the proportion of nests that likely had no incubating adults at the time of the drone survey. Data on nest attendance by Glaucous-winged Gulls can be used to estimate that proportion. Glaucous-winged Gulls sometimes exhibit broodiness in empty nests before eggs are laid, but the behaviour is uncommon (Vermeer 1963). It is thus appropriate to assume that incubating adults would be absent from empty nests, which would include those in which eggs have yet to be laid (or will never be laid), those from which eggs/chicks have been lost, or those which are empty later in the season after chicks have hatched and become mobile. The latter cause for empty nests was unlikely to pertain to the Lalach *et al.* (2023a) study, which was timed to occur before chick hatch, although in some years, hatch has been well underway by the date of that study. Glaucous-winged Gulls (Vermeer 1963, Verbeek 1993), like other large gulls (Drent 1970, Vermeer 1970), generally begin sitting on the nest after the first egg is laid, although effective incubation is infrequent until after the second egg is laid, and full incubation does not begin until the clutch is complete. Vermeer (1963) measured nest attentiveness in relation to clutch size at the large Glaucous-winged Gull colony on Mandarte Island, BC, which is located close to—and would experience similar ecological conditions as—the Chain Group colony where the Lalach *et al.* (2023a) study was conducted. In Vermeer's (1963) study, the percentage of time that adults sat on nests was 95.7% overall and averaged 74.6% after the first egg was laid, 94.6% after the second egg, and 99.0% after the third egg (percentages calculated from data in Vermeer 1963; $n = 12$ nests; 180 observation sessions totaling 540.3 observation-hours). If we assume that those percentages have not changed over time, they can be used to estimate the proportion of nests containing eggs that were likely without incubating adults present, given knowledge of nest contents at the time of the surveys.

Developing a conversion factor to account for the omission of incubating birds that were not detectable in the drone imagery of Great Chain Island because they were obscured by vegetation was more problematic. We are aware of only one preliminary study that evaluated proportions of nests visible from the air on different colonies (Blight 2023). That study was conducted on a small colony on nearby Arbutus Island, BC, (with ~45 breeding pairs in 2023), and data were inadequate to derive a meaningful conversion factor that could be applied elsewhere. In fact, more nests were counted on drone imagery of Arbutus Island than were counted during a land-based survey, suggesting that aerial surveys may sometimes detect nests that are obscured to surveyors on the ground. On the Chain Group, we did not observe many nests in obscured locations that would not be detectable on drone imagery. Most of the Chain Islets are bare, but about 8% of the area of Great Chain Island was covered with shrubs at the time of the survey (proportion calculated from Google Earth imagery). A map of cover types, including grassy, shrubby, and rocky covers, created by surveyors from the British Columbia Provincial Museum (now the Royal British Columbia Museum) in 1978 (BCWS 2005) suggests that the proportion of Great Chain Island covered with shrubs has not changed much since then. In 1978, observers kept track of how many nests occurred in each cover type, and only one nest was found in shrubby areas. Observers in 1978 noted that some nests may have been missed in tall grasses, but our recent observations suggest that nests on Great Chain Island that are obscured to ground surveyors by tall grasses are likely to be open to the sky and would be visible on drone imagery. Thus, although we lacked data to develop a conversion factor for obscured nests with incubating adults that may not have been detected on drone imagery of Great Chain Island, we suspect that the proportion of such nests on that island was small.

Data compilation

All historical survey data for the Chain Group were compiled by Rodway *et al.* (2024). Original sources for those data included the British Columbia Nest Record Scheme (BCWS 2005), Campbell (1976), Vermeer & Devito (1989), Blight (2014), and field notes from Louise K. Blight (unpubl. data). For the present study, data were included only from surveys conducted in June (to correspond with the Lalach *et al.* (2023a) study) in which all nests were counted and all nest contents were recorded. Original data sources were revisited to extract complete details on nest contents from those surveys.

RESULTS

Complete nest counts with records of nest contents on the Chain Group or just on Great Chain Island from surveys conducted in June were available for nine years between 1968 and 2009 (Table 1). The proportion of empty nests ranged from 3% in 1977 to 32% in 2009. Years with the highest proportions of empty nests also tended to have higher proportions of 1-egg clutches (16% in 2009).

Annual differences in clutch-size distributions were likely related to survey timing, yearly differences in laying phenology, and decreases in clutch size that have been observed in recent years (Blight 2011); these differences complicated the development of conversion factors for any particular year. To accommodate the observed variation in clutch-size distributions, we derived conversion factors using data from the most recent comparative survey in 2009, which had the highest proportions of empty and 1-egg clutches, and from the overall proportions of empty, 1-egg, 2-egg, and 3-egg clutches. These overall proportions were calculated by summing the number of nests within each clutch size across all years (Table 1). We then used observed nest-attendance data in relation to clutch size from Vermeer (1963) and multiplied both the 2009 totals and cumulative totals from all years by the respective estimated attendance rate for each clutch size. This calculation indicated that the overall proportion of nests likely to have adults sitting at the time of a drone survey in June was 63% if the timing of laying was similar to 2009 and 84% if the timing of laying was typical of the average timing from 1968 to 2009. These percentages were used as conversion factors to provide a range of adjusted breeding-population estimates. Empty nests accounted for most of the nests without incubating adults, which we estimated at 37% in 2009 and 16% over all survey years. Estimated numbers of nests with eggs that were unattended accounted for 6% of all nests in 2009 and 4% over all survey years.

A total of 1012 incubating adults were counted on Great Chain Island from the 2019 drone imagery (Lalach *et al.* 2023a). Applying the above conversion factors resulted in a total estimate on Great Chain Island of 1616 nests if the timing of laying was similar to 2009 and 1201 nests if the timing of laying was typical of the average timing from 1968 to 2009. During the most recent complete survey in 2009, the total number of nests counted was 1539 on Great Chain Island and 527 on the rest of the Chain Islets (Rodway *et al.* 2024, L.K. Blight unpubl. data). Assuming similar proportions nested in those two areas in 2019, the above conversion factors yield a total nesting-population estimate on the Chain Group colony of 1612–2169 pairs or 3224–4338 breeding individuals in 2019.

DISCUSSION

The use of mixed metrics has been identified as a problem that has frequently biased the assessment of biodiversity responses to habitat changes (Liu *et al.* 2023). The present study has identified an incipient, mixed-metrics problem related to the use of drone imagery when assessing population size and trends of colonial-nesting seabirds, which biases the evaluation of criteria for designating KBAs or other conservation assessments. Issues with the use of different metrics are likely to arise whenever new technologies are introduced and continuity with historical data is required.

Our results provide a conversion factor that at least partially translates counts of incubating Glaucous-winged Gulls detected on drone imagery to estimates of the total number of breeding pairs on a colony determined using ground surveys. Compensating for only nests without incubating adults, it appears that the number of incubating adults detected by drone likely represents 63%–84% of the total number of breeding pairs. Applying this conversion gave a range estimate of 3224–4338 breeding individuals for the population. This range well exceeds the national KBA criteria and brackets the recommended continental and global KBA criteria for Glaucous-winged Gulls. It thus changes the former conclusion (Lalach *et al.* 2023a) about whether the Chain Group colony meets the criteria for designation as a national or global KBA for Glaucous-winged Gulls.

To derive a conversion factor related to nests without incubating adults, we used data on nest contents and clutch sizes across nine surveys conducted during June over a 40-year period. Those data

TABLE 1

Numbers and contents of Glaucous-winged Gull *Larus glaucescens* nests counted during surveys conducted in June on the Chain Islets and Great Chain Island in British Columbia, Canada, between 1968 and 2009

Date	Nest contents						Total nests
	Empty	**1 egg**	**2 eggs**	**3 eggs**	**4 eggs**	**Other**[a]	
04 June 1968 (Great Chain Island only)	45	89	170	450	0	0	754
22–23 June 1973	60	74	341	954	3	116	1548
11 June 1974	105	152	379	1121	6	1	1764
30 June 1976	201	130	231	484	8	771	1825
20 June 1977	49	115	231	1331	3	109	1838
09 June 1978	198	223	489	1044	2	0	1956
28 June 1979 (Great Chain Island only)	151	97	278	654	0	654	1834
05 June 1981	373	209	374	923	1	0	1880
19 June 2009	656[b]	334	467	593	3	13	2066
CUMULATIVE TOTALS	***1838***	***1423***	***2960***	***7554***	***26***	***1664***	***15 465***
MEAN PERCENT OF TOTAL NESTS	***12***	***9***	***19***	***49***	***0***	***11***	***100***
Percent of nests likely with incubating adults (from Vermeer 1963)	0	74.6	94.6	99.0	100	100	
Numbers of nests likely with incubating adults in 2009	0	249	442	587	3	13	1294 (63%)
Cumulative numbers of nests likely with incubating adults from all years 1968–2009	0	1062	2801	7475	26	1664	13 028 (84%)

[a] Other nest contents included nests with at least some hatched young or nests with an uncountable number of depredated egg remains. Nests where all young were away from the nest were classed as empty.

[b] Empty nests were not included in the data presented by Blight (2014) nor were they used by Blight *et al.* (2015) and Lalach *et al.* (2023a). Empty nests were counted during the 2009 survey and have been included here (L.K. Blight unpubl. data).

are likely representative of inter-annual variation in nest contents that can be expected during surveys conducted at that time of year. In fact, some studies demonstrated similar or higher variability in the number of eggs laid per nest and in the proportion of empty nests among colonies (within the same year and between consecutive years; e.g., Lewis *et al.* 2017) than was seen in the Chain Group data across 40 years. Using all available historical data for the Chain Group thus generates broadly applicable conversion factors that provide a conservative range of adjusted population estimates. We also used attendance data in relation to clutch size, which was available from only one study (Vermeer 1963) conducted 60 years ago; data were based on a small sample of nests but many observation hours. Average clutch sizes may have changed since Vermeer's study (Blight 2011), and attendance patterns in relation to clutch size may also vary across years. More recent observations on the same colony studied by Vermeer suggested a lower rate of inattentiveness, especially for 1-egg clutches (L.K. Blight pers. comm.). However, recent studies of other gull species have shown rates of nest attendance by incubating adults similar to those found by Vermeer (1963). For example, camera monitoring of incubating European Herring Gulls (*L. argentatus*) with 1-egg, 2-egg, and 3-egg clutches at a Lake Superior colony found that adults were sitting on or were adjacent to their nests 95% (range: 80.8%–99.7%) of the time during the day (Serré *et al.* 2022). Further study is needed to elucidate variation in the nest-attendance behaviour of incubating adults; however, differences in attendance would not substantially affect our derived conversion factor, which mostly adjusted for empty nests that were not visible on drone imagery.

We did not develop a conversion factor to account for nests with incubating adults that may not have been detected on drone imagery because they were obscured by vegetation. The proportion of such nests would depend on the type of vegetation cover present and the propensity for birds to nest under such cover (Dickens *et al.* 2021). Our observations indicated that there were likely few obscured nests on the Chain Group colony. The problem would be greater on colonies with larger areas of dense vegetation. Changing fire regimes on large gull colonies like Mitlenatch Island in BC's Salish Sea have favored the growth of luxuriant grass and shrub cover (Rodway *et al.* 2024). During a recent survey of that colony, observers noted increased difficulty in finding nests built in dense vegetation and speculated that nesting birds may be preferentially selecting obscured nesting locations to gain protection from Bald Eagles *Haliaeetus leucocephalus* (Rybar 2022). Pairs nesting in well-hidden locations would likely not be detectable on drone imagery, but the proportion of birds nesting in such locations was not estimated. Determining the proportion of nests that would not be detectable on drone imagery would require surveying sample plots in different vegetation types both by drone and by thorough ground searches (Edney *et al.* 2023). Alternatively, if estimates of nesting density in different habitats could be derived on each colony, then the likely proportion of obscured nests could be calculated from the proportion of each habitat type on the colony.

In this study, we also did not consider possible sources of error related to accurately discriminating birds on nests from birds not on nests or to failing to detect nests during processing of drone imagery. The likelihood of those kinds of errors was considered low in the Lalach *et al.* (2023a) study, but it may be more relevant when drone surveys involve a greater number of birds (Edney *et al.* 2023). Discriminating birds on drone imagery is also more difficult with backgrounds that provide less contrast with nesting birds.

We have identified biases in data from drone imagery that compromise comparability with population estimates derived from ground surveys. However, it is useful to note that there are also potential biases in total-count population estimates determined by ground surveys. Double counting, missing nests, and misidentification of nests can introduce errors into total counts (Bibby *et al.* 2000). Those types of errors can be minimized with observer training and techniques to keep track of both areas that have been searched and nests that have been counted. We did not attempt to correct for any underestimation of nesting pairs that might occur due to observer error during a ground count. Therefore, it is possible that drone-derived imagery in some cases provides a more complete count of surface-nesting birds (Hodgson *et al.* 2018, Blight 2023).

Another source of bias in ground counts can be introduced if some pairs build more than one nest prior to laying. This bias is more challenging to address at present because it is difficult to quantify without detailed study. Glaucous-winged Gulls may start several nest scrapes (Vermeer 1963), but generally only one nest is completed (Verbeek 1993). Even if a second nest is built, repeated surveys within the same season on Franklin Island in the Strait of Georgia, BC, found that completed nests that are no longer in use are usually quickly demolished by the activities of nesting birds (Rodway *et al.* 2024). However, in a recent unpublished study, Blight (pers. comm.) observed that Glaucous-winged Gull pairs built or partially built one or more extra nests that persisted through the incubation period. These would have been counted as empty nests during ground surveys conducted during that time. Overall, we consider the possible bias caused by the persistence of extra nests to be small for this species in general, although it may be a significant source of error on some colonies in some years (L.K. Blight pers. comm.). A second bias related to nest building is also worth considering: as noted in the Methods, birds sometimes lay eggs on a scrape with little or no accumulated nesting material. Many nests like this were observed on Franklin Island and the adjacent Merry Island when those islands supported large gull colonies in the 1970s and 1980s (Rodway *et al.* 2024). Without eggs, such scrapes would not be counted as nests according to standard protocols. This introduces a potential bias that would contribute to underestimating actual breeding-population sizes, assuming that there are at least some empty scrapes where eggs eventually would be laid. Observers on Mitlenatch Island in 2022 counted 143 empty scrapes that were not included in the total nest count for that year (Rybar 2022). Some of those scrapes may have represented breeding pairs that had not yet laid eggs at the time of the survey. Underestimating numbers of nesting pairs by excluding empty scrapes that are yet to receive eggs would counter overestimation due to pairs building multiple nests.

Acknowledging the potential biases in ground counts due to pairs building multiple nests or laying eggs in scrapes with no nesting materials, it is still essential that measurement units are used consistently to maintain comparability of data across time and among colonies. Because the standard methodology for counting gull nests is to include all at-least-partially-built-up nests detected during ground surveys, and because population estimates at national and global scales are derived using those methods, it is appropriate that the same measurement units are used to assess sites being considered for designation as KBAs. Conversion factors, like those developed here, are thus required to adjust counts of incubating adults derived from remote imagery before those counts can be used to evaluate candidate sites.

If drone surveys become the prevalent method for assessing population sizes on colonies of Glaucous-winged Gulls and other surface-nesting seabird species, greater consideration would be required of the potential biases in the resulting data than we have given here. Conversion factors to correct for nests without incubating or brooding adults will still be required to generate accurate estimates of breeding-population size, unless image resolution improves enough that such nests can be reliably distinguished on photographs gathered by drone. However, the bias due to not detecting empty or unattended nests becomes more problematic, and the conversion factors developed in this study may not be adequate if drone surveys become more common. There are many situations that generate high proportions of empty nests on colonies, including egg harvesting by First Nations groups, disturbance by recreational boaters, harassment by Bald Eagles, delayed laying phenology, and abandonment of breeding efforts due to food shortages. Evidence of such disturbances or impacts is often obvious to ground surveyors, who can still proceed to count empty nests (e.g., Vermeer *et al.* 1991), but such evidence may not be apparent in drone surveys. For example, drone imagery could return a count of zero breeding birds on a colony from which all eggs had been recently harvested; the conversion factors developed in this study obviously would not accommodate such cases. As noted above, the problem of detectability of nests that are obscured by vegetation also becomes more pertinent when a greater variety of colonies and nesting habitats are surveyed by drone.

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