FINDING COLONIES OF BLACK-HEADED GULLS *CHROICOCEPHALUS RIDIBUNDUS* USING GOOGLE EARTH

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ABSTRACT

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We explore the possibility of identifying Black-headed Gull *Chroicocephalus ridibundus* colonies in the saltmarshes of the Lagoon of Venice, Italy, using Google Earth satellite images. One reproductive season was considered (June 2017), based on the images available on Google Earth. This species builds nests clustered around tidal pools and tidal creeks, providing a dark background to reveal the white gulls. Images of the southern part of the lagoon (excluding fish farms) were analyzed by dividing it into sectors ($n = 403$) using the Google Earth grid at an elevation of 100 m above ground level. The results of the satellite count were compared with field data collected in the same season. Image analysis revealed five colonies, with excellent sensitivity (100%) but only good specificity (88%), due to the presence of numerous clear areolae falling within the spectral range of nests; these consisted of plastic litter and dry, stranded vegetation. Overall, our results indicate that Black-headed Gull colonies can be found in marsh-island habitat using Google Earth. While this approach presents sub-optimal specificity due to both the abundance of whitish debris and low image resolution, future developments in software capabilities hold the potential to overcome these limitations and enhance the accuracy of the proposed approach.

Key words: Black-headed Gull, breeding, Google Earth, *Chroicocephalus ridibundus*, satellite imagery, Lagoon of Venice

INTRODUCTION

Long-term monitoring of breeding population size in seabirds plays a pivotal role in the assessment of ecosystem health, by means of providing population trend data (Chabot & Francis 2016). The efficacy of monitoring methods can be severely affected by difficulties in accessing both habitat and animals (Afán *et al.* 2018). This is particularly true for seabirds, especially those species, such as larids, whose spatial distribution extends uniformly across large areas of wetland. Accessing these areas often poses a challenge due to natural obstacles such as rocky cliffs, impenetrable marshes, or shallow lagoons with soft bottom substrate, all of which render their identification and exploration highly labour-intensive. Various methods have been adopted to conduct surveys, each with its own pros and cons. Traditional monitoring entails a significant disturbance to breeding seabirds caused by researcher presence in the colony. The effects of these disturbances are not yet fully understood and may even result in colony failure (Ibáñez-Álamo *et al.* 2012). Airplane photography has often been used to address challenges arising from the combined effects of limited accessibility and extensive study areas (Taylor & Wilson 1990, Taylor *et al.* 1990, Rexer-Huber *et al.* 2020). However, these surveys are subject to limitations, including high costs and inherent risks for researchers (Sasse 2003). Whereas the use of uncrewed aerial vehicles (also known as drones) has proven a timely alternative to solve disturbance issues, with most studies showing little to no response from the birds (Ellis-Felege *et al.* 2021, Rümmler *et al.* 2021, Geldart *et al.* 2022), there is still variation in response that depends on the monitored species (Marchowski 2021, de Leija *et al.* 2023). Thus, potentially stressful monitoring should be ground-truthed to mitigate potential negative impacts. An alternative approach is the use of satellite imagery, which has become progressively more common in census studies focusing on breeding waterbirds (Fretwell & Trathan 2009, Schwaller *et al.* 2013, Fretwell *et al.* 2017). Nonetheless, satellite imagery also shares the aforementioned limitations associated with aerial surveys in terms of restricted image resolution, particularly when monitoring inconspicuous species. This can result in an underestimation of population sizes as well as increased financial costs (Frederick *et al.* 1996).

Google Earth (https://earth.google.com; hereafter referred to as GE) has recently emerged as a valuable tool across many research fields (see Yu & Gong 2012 for a review), including the localization of colonies and individuals in conspicuous waterbird species. Examples include Masked Booby *Sula dactylatra* (Hughes *et al.* 2011), Mute Swan *Cygnus olor* (Valle *et al.* 2022), and Purple Heron *Ardea purpurea*; nests are identified by the presence of incubating birds or chick fecal remnants, which in turn facilitates the detection of breeding pairs (Valle *et al.* 2021).

Nest-detection methods using satellite imagery are particularly relevant in the context of the Lagoon of Venice in northeastern Italy, where seabirds have been systematically monitored each year since 1989. To date, eight species have been recorded, namely the Black-headed Gull *Chroicocephalus ridibundus*, Mediterranean Gull *Ichthyaetus melanocephalus*, Yellow-legged Gull *Larus michahellis*, Gull-billed Tern *Gelochelidon nilotica*, Sandwich Tern *Thalasseus sandvicensis*, Lesser Crested Tern *Thalasseus* *bengalensis*, Common Tern *Sterna hirundo*, and Little Tern *Sternula albifrons* (Scarton & Valle 2021). These species are distributed across fewer than 10 saltmarsh islets out of the hundreds in the lagoon, making the task of locating colonies challenging (Scarton & Valle 2015). In particular, Black-headed Gulls breed in the southern part of the lagoon, with a small population of ~100 pairs spread over an area of 300 km^2 (Scarton & Valle 2022). The species nests with a very characteristic pattern, building nests near the tideline, tidal pools, and tidal creeks on marsh islands (Scarton & Valle 2022). This nest-site preference is exclusive to this species; other species that are similar to the Black-headed Gull in both size and color, such as the Mediterranean Gull, did not nest in the Lagoon of Venice during the study year.

Given this context, we aimed to investigate the feasibility of using satellite imagery from Google Earth to identify colonies of Black-headed Gulls within the vast saltmarsh area of the Lagoon of Venice. Our findings demonstrate that, while it is still in its developmental stage, the method holds promise for wildlife monitoring, particularly in assisting researchers with the identification and monitoring of populations within known study areas.

METHODS

Study area

We conducted this study in the Lagoon of Venice (45°17′38.16″N, 012°11′14.73″E), the largest lagoon in the Mediterranean Sea at 55 000 ha (550 km^2). It features 4000 ha of saltmarshes, around 35 000 ha of shallow bottoms, and about 20 fish farms that cover an additional 9000 ha (Day *et al.* 2019; Fig. 1). The mean depth of the lagoon is 1.1 m and the tidal range during spring tides is ~1.0 m, with a mean tidal range of 0.6 m. The climate is temperate, with a mean annual temperature of 14.5 °C, and average rainfall is ~800 mm per year, with the peak in March and the minimum in May. The saltmarshes, which have elevation of 0.5–0.7 m above sea level, are regularly flooded during high tides. Dominant plant species include *Sarcocornia fruticosa*, *Salicornia veneta*, *Limonium narbonense*, *Halimione portulacoides*, and *Puccinellia palustris*.

All Black-headed Gulls build nests in the open, on the halophilic vegetation of the saltmarshes. Vegetation tends to be low (about 20–30 cm) and free of shrubs and trees. The nests are therefore easily visible. Nest-site selection is ruled by a combination of 1) proximity to the tideline, 2) elevation above water level, and 3) proximity to tidal pools and tidal streams (Scarton & Valle 2021).

The lagoon is an important site for breeding and wintering waterbirds (Scarton & Valle 2015). Because of this, most of the lagoon is included in Special Protection Area IT3250046 Laguna di Venezia, according to the European Community 147/09 Birds Directive. The study area comprised the southern part of the lagoon (a traditional breeding area for the species; Scarton & Valle 2021), which spans from the Malamocco Inlet (45°20′05.06″N, 012°19′38.53″E) to the mouth of the Brenta River (45°10′53.73″N, 012°19′02.08″E), excluding fish farms, which are of restricted access.

Surveys

Using the GE grid, we divided the study area into 697 sectors of 11.3 ha each, of which 403 were deemed suitable for Black-headed Gull nesting sites, i.e., they were not entirely covered by water during the average high tide. Then, using imagery taken

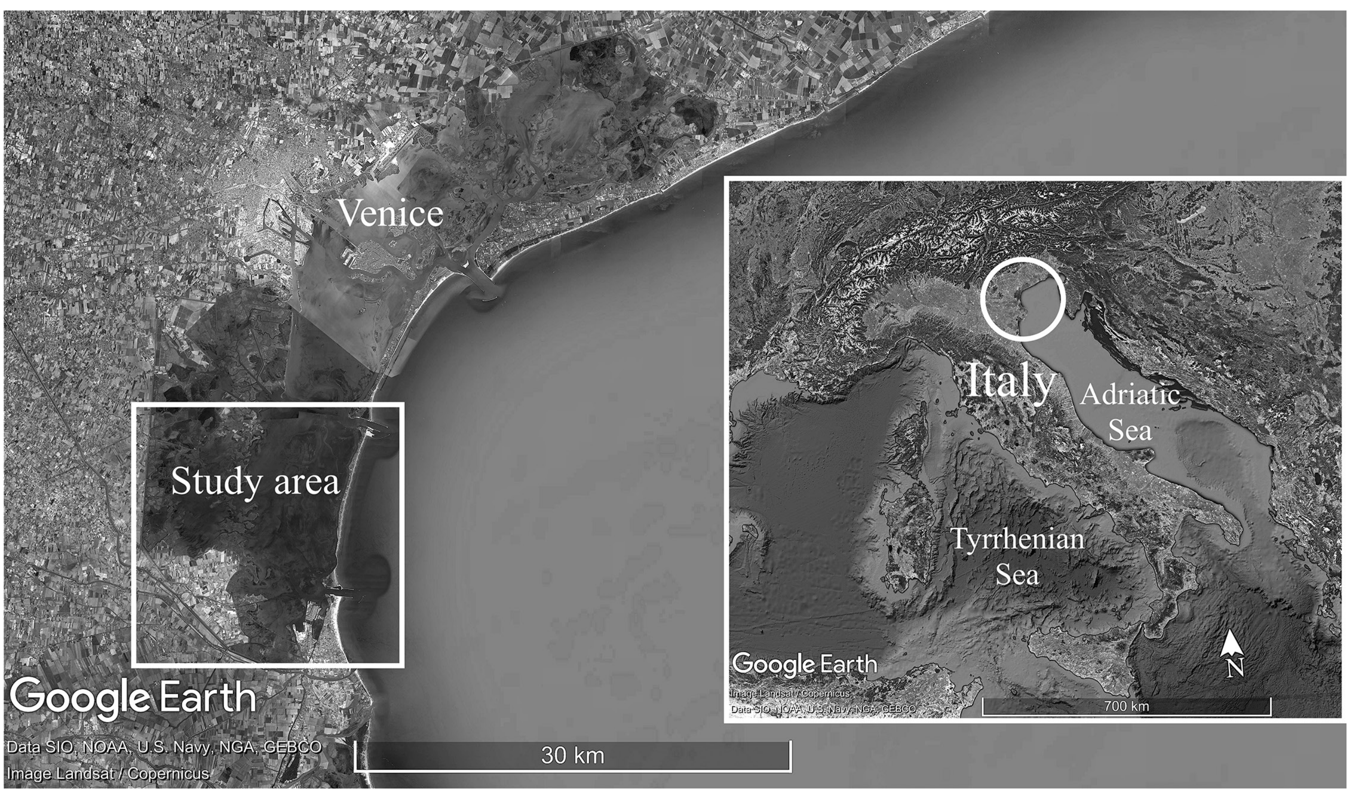

Fig. 1. Southern Lagoon of Venice, Italy, showing the study area. The right inset shows the study location relative to the coast of Italy.

on 22 June 2017, we estimated the number of occupied nests. We looked for approximately circular, whitish-beige spots with a diameter of 0.3–0.6 m, which is compatible with incubating birds (Figs. 1, 2). We assessed colonies as per Valle *et al.* (2021), who defined a "colony" as a group having more than five nest-like "spots". In addition, two more ancillary criteria were used for assessing Black-headed Gull nests: 1) located in suitable habitats (saltmarsh islets) within 5 m of a tidal creek or pond (Scarton *et al.* 1994) and 2) located a distance from the tideline of 5–30 m. All these criteria had to be met to classify an area as a true colony instead of a false positive. We adopted these ancillary criteria because an exploratory analysis showed that smaller aggregations of circular whitish-beige spots (usually plastic debris or dried stranded vegetation) were a common finding in GE imagery of the study area. Including these would cause a huge number of false positive cases, as previously observed for Purple Herons (Valle *et al.* 2021). To reach an adequate statistical power, isolated sub-colonies were treated as colonies.

To assess the reliability of GE counts, we used data from a series of ground, boat, and drone surveys conducted in 2017 (Scarton & Valle 2021). Our fieldwork effort took place within a broader framework of a long-term monitoring project of waterbirds breeding in the Lagoon of Venice that started in 1989 (Scarton & Valle 2015).

Statistical analyses

Using the colonies annotated in the GE imagery and the information obtained in the subsequent field surveys, we calculated i) sensitivity (i.e., proportion of actual positives that were correctly identified as such); ii) specificity (i.e., proportion of actual negatives that were correctly identified as such); iii–iv) positive and negative predictive values (i.e., proportions of positive and negative results that were true-positive and true-negative results, respectively); and v) overall accuracy (i.e., probability that an individual was correctly classified by a test: the sum of true positives plus true negatives divided by the total number of individuals tested, following Allouche *et al*. 2006). Differences in mean values were tested using a paired Student's *t*-test. Categorical data are presented as numbers (percentages), and continuous data are presented as means ± one standard deviation. A value of $P < 0.05$ was considered significant. Analyses were performed using SPSS Statistics (version 20, for Mac).

RESULTS

In total, we found candidates for Black-headed Gull colonies in 53 sectors of the southern part of the Lagoon of Venice. Of these, only five hosted true colonies or sub-colonies that were detected

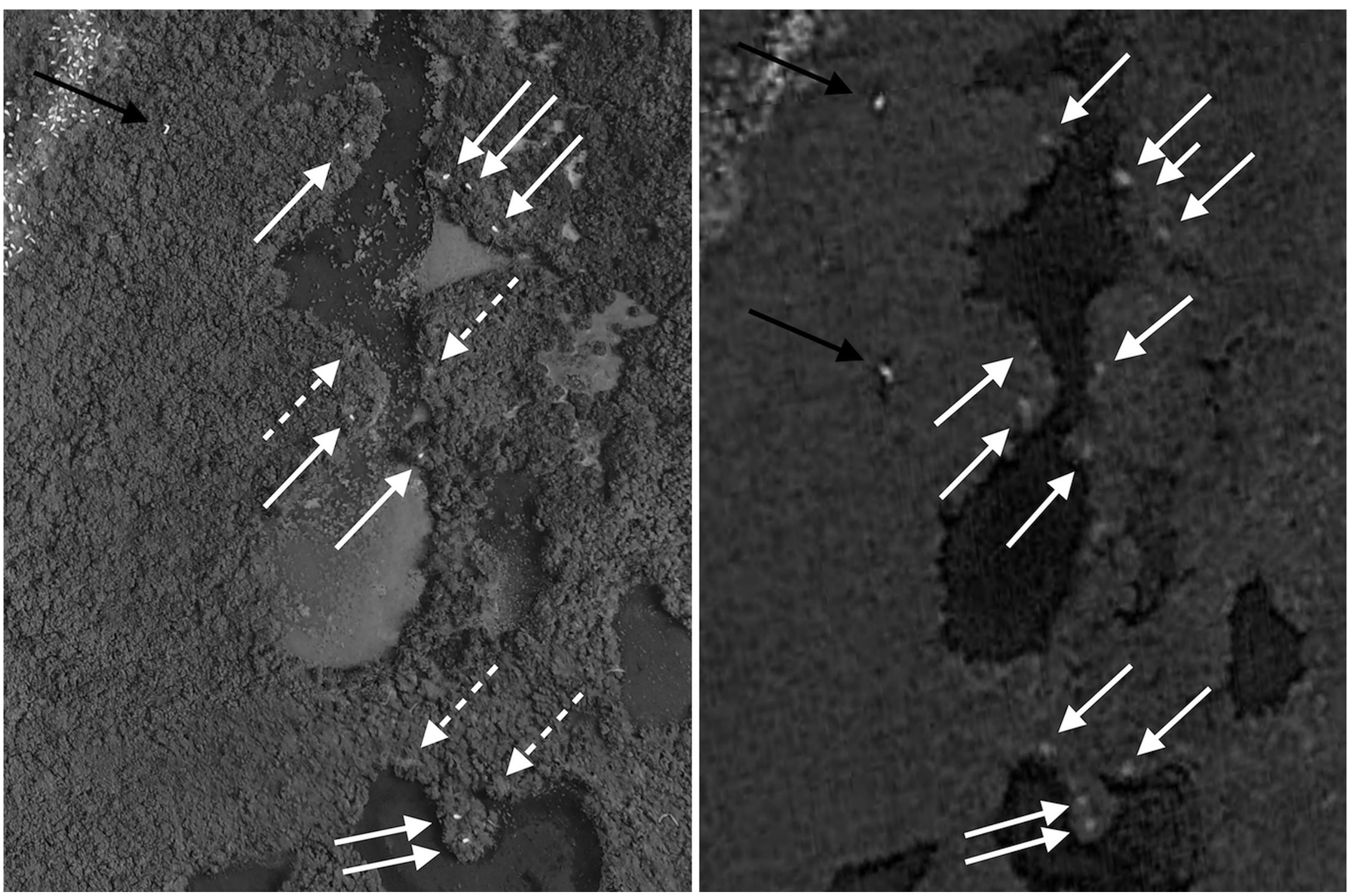

Fig. 2. Two images showing a colony of Black-headed Gulls *Chroicocephalus ridibundus* on a marsh island in the Lagoon of Venice, Italy, in June 2017. The left image is from a drone, and the right image is from Google Earth. Solid white arrows indicate nests of Black-headed Gulls found by drone surveys and/or Google Earth imagery searches. Dotted white arrows show nests that were not noticed during the drone flight but were confirmed during ground inspections. The short white arrow on the right image indicates a nest not visible on Google Earth. Black arrows indicate white debris.

during field surveys. Based on the abovementioned ancillary criteria (i.e., nests located in saltmarsh islets within 5 m of a tidal creek/pond and 5–30 m from the tideline), 36 and 7 colony-candidates, respectively, were excluded. The relevant number of false positives ($n = 48$) was due to stranded objects in the same spectral range of Black-headed Gull nests (e.g., white plastic debris and dried stranded vegetation). Thus, our proposed method provided optimal sensitivity (100%) and optimal negative predictive value (100%), but only good specificity (88%) and fair overall accuracy (88%; Table 1). Colony size was not significantly different between GE and field counts: 22 ± 19 pairs vs. 27 ± 33 pairs, respectively. We performed a paired *t*-test on the square-root-transformed variable: $t = -0.675$, $P = 0.636$, $n = 5$.

TABLE 1
Confusion matrix for Google Earth counts, relative to ground surveys of Black-headed Gulls in the Lagoon of Venice, Italy, in 2017

	Ground count	
Google Earth count	**Absent**	**Present**
- Absent	350	0
- Present	48	5

DISCUSSION

In this study, we showed that Google Earth can be effectively used as a supplementary tool to detect Black-headed Gull colonies in marsh-island habitats such as the Lagoon of Venice. Its use offers a convenient and rapid approach with a satisfactory overall accuracy rate of 88%. These findings build upon previous evidence supporting the feasibility of using free satellite imagery for counting nesting waterbirds (Hughes *et al.* 2011; Valle *et al.* 2021, 2022). In particular, our results confirm the suitability of GE for detecting the location and extent of seabird colonies, similar to results previously observed for penguins (Schwaller *et al.* 2013), albatrosses (Fretwell & Trathan 2009), petrels (Schwaller *et al.* 2018), and herons (Valle *et al.* 2021).

In the case of Black-headed Gulls, their peculiar nest-habitat selection behaviour, which restricts nest location to within a few meters (< 5 m, but typically < 1 m; Scarton *et al.* 1994) of tidal creeks or ponds and in close proximity to the tideline, greatly facilitates colony detection on GE imagery. In perspective, this behaviour could allow the distinction of Black-headed Gull colonies from those of other species within the same spectral range, such as Mediterranean Gulls, whose nests are in closer proximity to each other and are not necessarily close to tidal creeks and ponds (RGV and FS, pers. obs.).

The real effects of researchers entering seabird colonies is still under investigation (Ibáñez-Álamo *et al*. 2012), but the possibility of locating colonies and counting nests without flushing incubating birds and nestlings and without trampling or damaging the halophilic vegetation is a tempting prospect. Thus, the proposed method, by being non-intrusive for both birds and researchers, presents an appealing alternative, as it avoids both disturbing birds and damaging the vegetation within colonies. However, it should be noted that the current spatial resolution provided by GE does not permit the accurate detection of Black-headed Gull colonies. It is to be expected, however, that the resolution of GE imagery will improve over time, as it has since its first availability

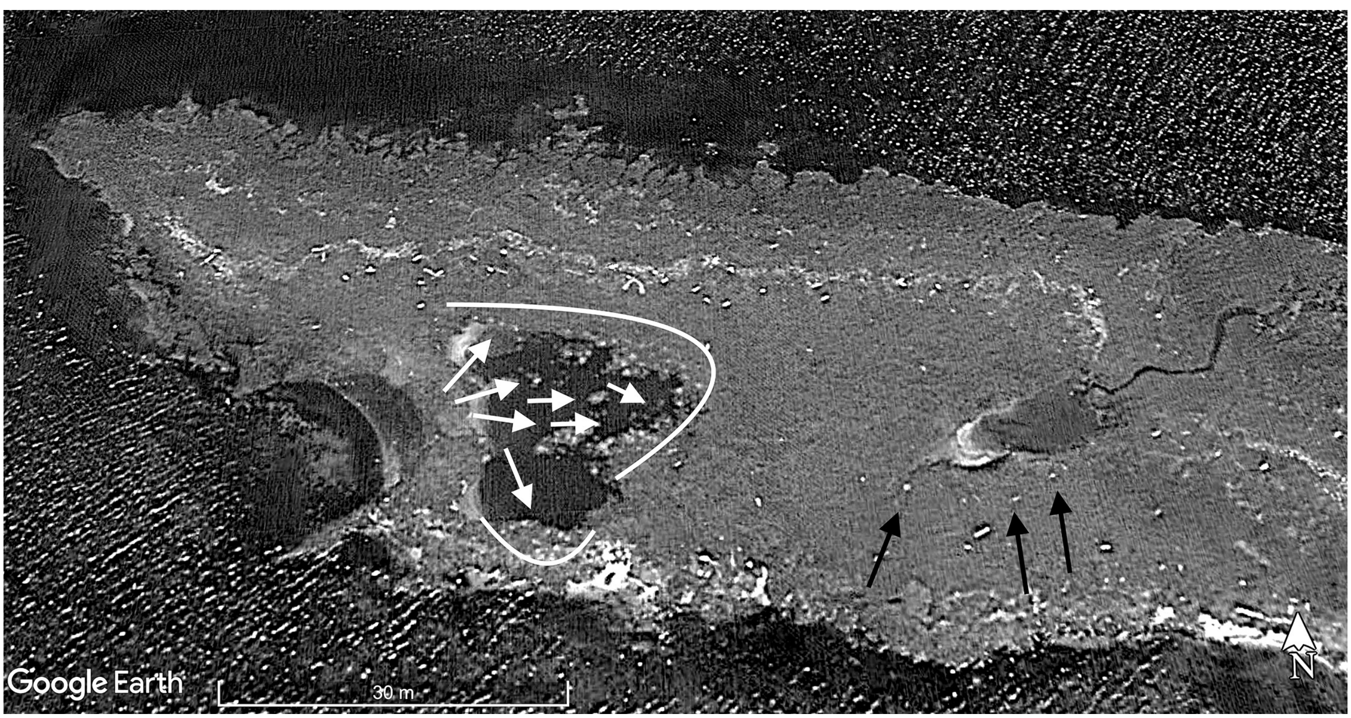

Fig. 3. Google Earth imagery showing a true colony of Black-headed Gulls *Chroicocephalus ridibundus* (lines delimit the area of the colony, whereas white arrows indicate nests) and false positives caused by white debris (black arrows) on a marsh island in the Lagoon of Venice, Italy, in June 2017.

on the web. These advancements may facilitate overcoming the abovementioned obstacles to accurately census waterbirds, as reported with the use of super-high-resolution satellite imagery (Fretwell *et al.* 2017). Increased resolution could allow the use of additional improvements to GE imagery, such as software for counting seabirds, by adopting semi-automated counting tools. The latter have been widely employed with satellite, aerial, and drone imagery (Descamps *et al.* 2011, Chabot & Francis 2016, Valle 2022).

The proposed approach for counting Black-headed Gull colonies is a low-cost and time-efficient method, with the entire 70 km^2 area being searched in just 6.5 hours. Moreover, and because it relies on a freely accessible website, this method could become an ideal tool for researchers, particularly in the context of large-scale census programs. In this regard, we would like to emphasize the role of citizen scientists, who can provide a relevant contribution to the advancement of knowledge by gathering field data (Mayfield 1979).

Our study acknowledges three limitations. First, the main limitation is the need for prior knowledge about the spatial arrangement of Black-headed Gull nests within colonies, which is acquired during ground inspections; this information is

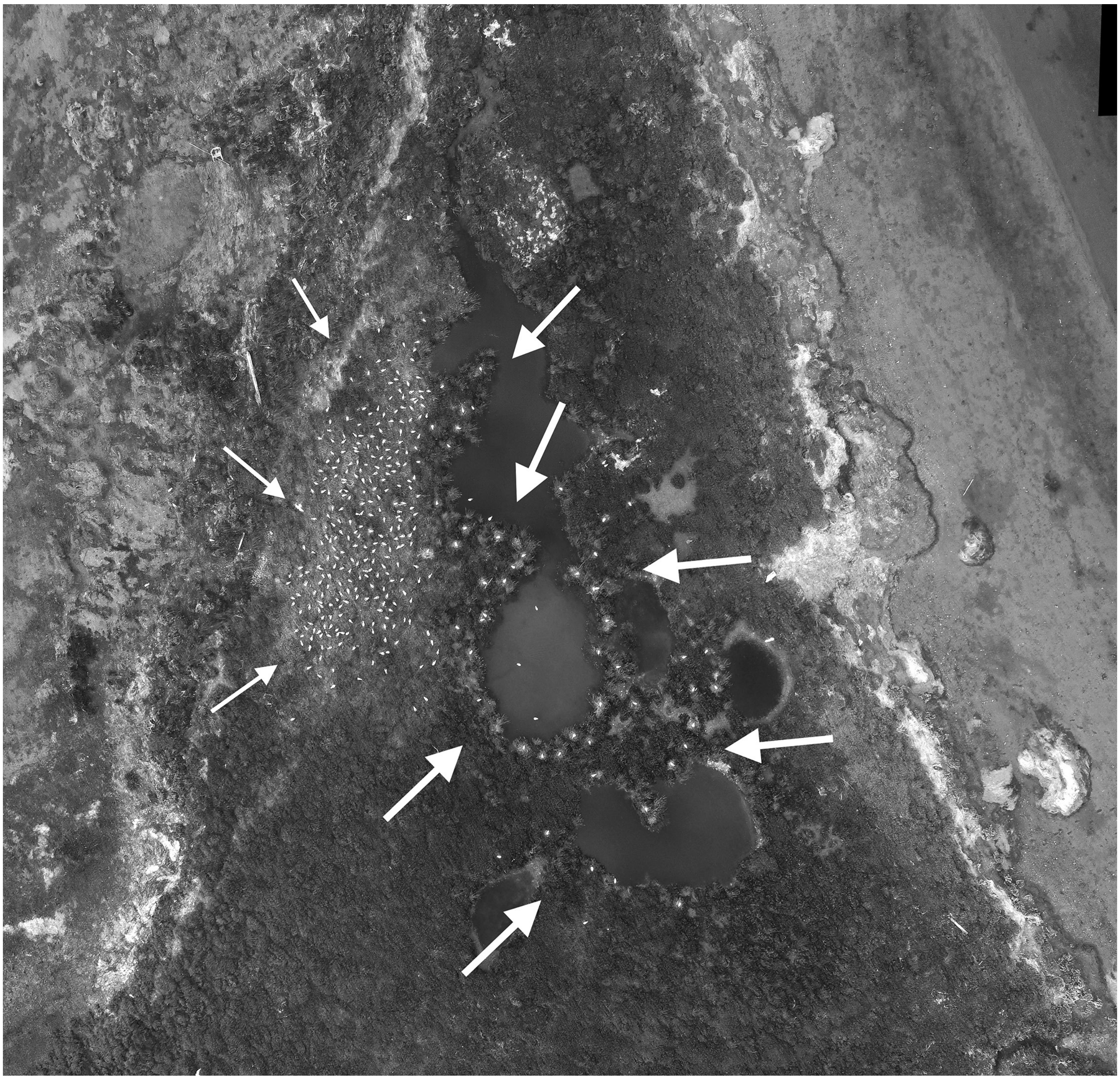

Fig. 4. Drone imagery showing a mixed colony of Mediterranean Gulls (*Ichthyaetus melanocephalus*, thin arrows on the left) and Black-headed Gulls (*Chroicocephalus ridibundus*, thick arrows on the right) on a natural marsh island in the Lagoon of Venice, Italy, in mid-May 2021. Species-specific nest distribution patterns and density are evident, especially the proximity of Black-headed Gull nests to shorelines.

essential to correctly recognize groups of actual nests on GE imagery. One of the authors of this study (ACC), who did not participate in the fieldwork, failed to identify Black-headed Gull colonies in the GE images used in our study, highlighting the importance of ground inspections to verify the satellite imagery. This limitation could be overcome if satellite images were available in real time, which researchers could then use as a screening tool to reduce the size of the fieldwork area for colony detection. Unfortunately, GE imagery is currently published some months after the photos are taken, which prevents its use by researchers for visiting GE-detected colonies within the same breeding season. However, Black-headed Gulls (as well as Laridae in general, but not many tern species nest in ephemeral habitat; Coulson 2016) are known to be philopatric both in our area (Scarton *et al.* 1994) and others (Flegg & Cox 1972). The location of colonies does not vary much from year to year, so new colony sites can be included in future studies in the same area. Second, accuracy in nest detection using the proposed method is sub-optimal due to poor specificity caused by the great abundance of whitish debris (which has the same spectral properties of gulls) in the lagoon (RGV pers. obs.). Thus, when interpreting and using data from satellite surveys of prospective colony habitat, caution should be used—as for any innovative technique—to give data the right weight and avoid under- or over-estimations (Southwell *et al.* 2017). Finally, the accuracy of our proposed method resides in the absence of species similar to Black-headed Gulls breeding in the Lagoon of Venice during the study periods. It could be easily assumed that our method could not have distinguished between different gull species if Mediterranean Gulls had bred in the lagoon in 2017. This is something to test in the future.

This study shows that it is possible to find colonies of Black-headed Gull in the marsh islands of the Lagoon of Venice using Google Earth. Nevertheless, the proposed approach presents current sub-optimal specificity due to the abundance of whitish debris and low image resolution. Future developments in software capabilities hold the potential to overcome these limitations and enhance the accuracy of the proposed approach.

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