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Ornis Hungarica 2022. 30(2): 176–187.
DOI: 10.2478/orhu-2022-0028

Drone monitoring improves nest detection of Squacco Herons *Ardeola ralloides*, but fails to assess its productivity

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Received: August 19, 2022 – Revised: October 24, 2022 – Accepted: October 25, 2022

Valle, R. G., Corregidor-Castro, A., Verza, E. & Scarton, F. 2022. Drone monitoring improves nest detection of Squacco Herons *Ardeola ralloides*, but fails to assess its productivity. – Ornis Hungarica 30(2): 176–187. DOI: 10.2478/orhu-2022-0028

Abstract In the last decade, the use of drones has proven to be the major innovation for studying various aspects of waterbird breeding biology, overcoming the environmental obstacles inherent in monitoring their breeding sites. The Squacco Heron *(Ardeola ralloides)* represents an example of the aforementioned difficulties, since it nests in impenetrable reed beds and nearby bushes, trees and shrubs. The present work reports the results of drone assessment of nest counting and reproductive success of the Squacco Heron in a colony in the Po Delta (NE Italy). At the beginning of the breeding season, far more nests (46) were found using drones than by eye from the nearest embankment (12). After four weeks (estimated hatching period), only ten nests were relocated by drone, due to vegetation overgrowth. All relocated nests were placed directly either within reed beds or on lower branches of shrubs, but always without higher branches obstructing the view from above. Finally, in the fledging period, no nest was relocated on drone imagery, due to further vegetation growth. Only 27 juveniles were found by drone, mostly perching on the canopy, without any evidence of nest failure, suggesting a critical underestimation. In conclusion, drone use improves accuracy of counting nesting Squacco Herons, but fails to assess productivity.

Keywords: counting, disturbance, drone monitoring, productivity, Squacco Heron

Összefoglalás Az elmúlt évtizedben a drónok használata bizonyult a fő innovációnak a vízimadarak költésbiológiája különböző aspektusainak tanulmányozásában, leküzdve a fészkelőhelyeik megfigyelésében rejlő környezeti akadályokat. A selyemgém *(Ardeola ralloides)* a fent említett nehézségek egyik példája, mivel áthatolhatatlan nádasokban és az azokban levő bokrokon, fákon fészkel. Jelen munka a Pó-deltában (Észak-Olaszország) található kolóniában a selyemgém fészekszámlálása és szaporodási sikere drónvizsgálatának eredményeiről számol be. A költési időszak elején jóval több fészket (46) találtak drónok segítségével, mint a legközelebbi töltésről megfigyelve (12). Négy hét (becsült kelési időszak) után csak tíz fészek volt azonosítható a drónok által a növényzet túlburjánzása miatt. Valamennyi újra megtalált fészek közvetlenül a nádasban vagy a cserjék alacsonyabb ágain helyezkedett el, mindig anélkül, hogy a magasabb ágak akadályoznák a rálátást felülről. Végül a kirepülési időszakban a drónfelvételeken egyetlen fészket sem került azonosítani a növényzet további növekedése miatt. Csak 27 fiatal madarat találtak drónnal, többnyire a lombkoronában állva, anélkül, hogy a fészek meghibásodására utaló bizonyítékot észleltek volna, ami jelentős alulbecslésre utal. Összefoglalva, a drónok használata javítja a fészkelő selyemgémek számlálásának pontosságát, de nem tudja felmérni a költési sikert.

Kulcsszavak: számlálás, zavarás, drón megfigyelés, termékenység, selyemgém

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Introduction

Long-term monitoring of breeding birds is fundamental to understand the health status of the ecosystem they thrive in (Şekercioğlu *et al.* 2004). Aerial surveys have long been used for studying breeding waterbirds, which frequently nest in areas characterized by scarce accessibility and/or huge extension, both in the past using fixed-wing aircraft (Henny *et al*. 1972) and in recent times with drones (Mulero-Pázmány *et al*. 2017). Drones overcome the limitations of traditional fixed-wing aircraft surveys, which are expensive and often impractical, thus being restricted to professional ornithologists or academic researchers and even dangerous (Sasse 2003).

Growing evidence is showing the extraordinary capabilities of drones in the study of reproductive biology and in particular various aspects of breeding success of birds (Junda *et al.* 2015, Weissensteiner *et al.* 2015, Gallego & Sarasola 2021). This is particularly true for waterbirds, as drones have proven to be as (and in some cases even more) accurate as traditional ground-based approaches (Dundas *et al.* 2021, Valle & Scarton 2021), while reducing the disturbance caused in the breeding grounds (Brisson-Curadeau *et al.* 2017, Sardà-Palomera *et al.* 2017, Valle & Scarton 2019a).

In addition, one issue that drones have shown to solve is related to the accessibility of the monitoring areas. One of the main inherent obstacles in monitoring waterbirds is the presence of nests in environmental settings that make traditional land or boat access difficult, if not impossible (Scarton & Valle 2020). Several studies have shown the possibilities of monitoring in inaccessible areas (Afán *et al.* 2018, Scarton & Valle 2020, Dundas *et al.* 2021, Dunn *et al.* 2021). However, the enthusiasm for the results obtained with the use of drones can overshadow the limitations of the method, which have been highlighted by some recent works (Afán *et al.* 2018, Valle & Scarton 2020), in particular when vegetation cover is high (McKellar *et al.* 2021). It is therefore fundamental to test the drone approach on as many species and environmental contexts as possible, in order to assess methodological constraints.

The Squacco Heron *(Ardeola ralloides)* is a marsh dwelling waterbird found in fresh water habitat with abundant marsh vegetation, mainly reed beds and nearby bushes, trees and shrubs. Because their nests are typically built in dense thickets of trees or shrubs frequently placed less than two meters above water level (AWL) within single- or mixed-species colonies (del Hoyo *et al.* 1992, Kushlan & Hancock 2005), it represents an optimal example of species breeding in a difficult monitoring area. In Europe, the Squacco Heron is present with about 15,000–25,900 nesting pairs (BirdLife International 2022). In Italy, where the species presents a conservation status of near threatened (BirdLife International 2022), the breeding population is concentrated in the inner and coastal Po Plain, mainly in the western part (Brichetti & Fracasso 2018), with the most recent estimates giving a figure of 314–461 pairs (Ercole *et al.* 2021). In the eastern Po Plain, the species is scarce; for instance, in the Veneto region only 27–29 pairs were censused in 2020 (Verza *et al.* 2021).

In 2021, the establishment of a fair-sized colony of Squacco Heron in a floodplain of the northern Po Delta (NE Italy) offered the opportunity to test the possibility of studying the breeding biology of the species using drones. The present work reports the results of drone assessment of nest counting and reproductive success measurement of the Squacco Heron, quantifying disturbance to breeders as a secondary endpoint.

Materials and Methods

Study Site

Fieldwork was conducted during the 2021 breeding season, in a heronry of the Po Delta along the northern Adriatic coastline within the framework of a broader project aimed at monitoring the breeding species of herons (Verza *et al.* 2021). We counted nests of Squacco Heron in a mixed colony of Ardeidae (Cattle Egret *Bubulcus ibis*, Little Egret *Egretta garzetta*, Night Heron *Nycticorax nycticorax*, Purple Heron *Ardea purpurea*) and Pygmy Cormorant *(Microcarbo pygmaeus)* for overall 591 nests located on a 0.14 ha muddy islet on a floodplain of the Po di Maistra river (44°58'34.21" N, 12°20'18.19"E). The islet was covered with small trees of false indigo-bush *Amorpha fruticosa* with a maximum height of 3.5 m, surrounded by a strip of common reed *Phragmites australis*. It laid 60 m from the western river embankment, thus being clearly visible from the latter *(Figure 1)*. The islet was virtually inaccessible: it was a few centimeters above the water level and made of soft mud, being surrounded by a large, shallow (<10 cm) waterbody with very soft bottom.

Field procedures

In total, we conducted eight weekly surveys. In order to compare accuracy between traditional (i.e. by eye) and drone methods, we conducted paired surveys from the nearest embankment on the first two visits in mid May, when surveys were conducted alternating the order of the methods to avoid observer-bias or other influences in disturbance. We considered drone counts as ground truth due to its high accuracy in nest detection, as previously shown in several studies (Chabot *et al.* 2015, Hodgson *et al.* 2016, Pöysä *et al.* 2018, Valle & Scarton 2022). Nests were mapped on a drone image of the colony *(Figure 1)* to be checked at subsequent visits. Then, nests were checked weekly from early May to late June and then on mid-July exclusively using drones in order to assess hatching and fledging success respectively. We used a small off the shelf drone (DJI Mini2), with the following parameters: weight 249 g, maximum speed 35 mph (56 km/h), flight time 31 min, sensor 1/2.3″, lens 24 m, f/2.8, 4K camera. No ground surveys within the colony were conducted in order to avoid disturbance to the incubating birds that could ultimately lead to abandonment or even colony failure. Nests were searched and monitored flying at elevations of 15 m above ground level (AGL), which have been shown to be higher than the agitation distance (i.e. adults opening wings to cover eggs and/or newly hatched chicks in response drone intrusions) for the species (Valle & Scarton 2018). According to current recommendations (Hodgson & Koh 2016, Valle & Scarton 2018), the drone was launched at least at 150 m

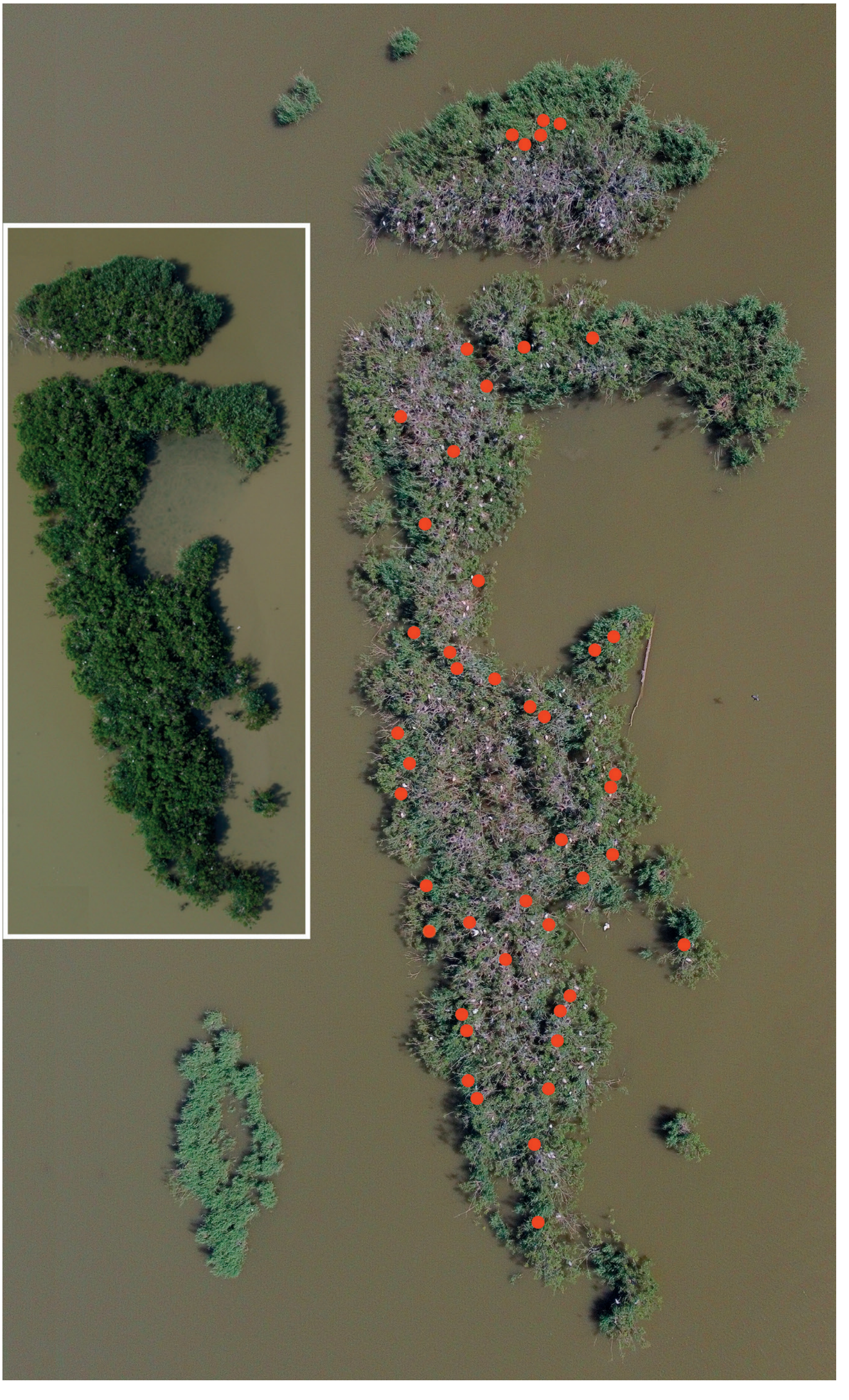

Figure 1. Study site (Po Delta – NE Italy, breeding season 2021). Orange circles indicates nests of Squacco Heron. A clear preference for placing nests in reed beds, rather than in shrubs, is evident. Left inset shows vegetation overgrowth in mid-June

1. ábra Vizsgálati hely (Pó-delta – ÉK Olaszország, költési szezon 2021). A narancssárga körök a selyemgémek fészkeit jelzik. Nyilvánvaló, hogy a fészket inkább a nádasba építik, nem a bokrokra. A bal oldali bevágás a növényzet túlnövekedését mutatja június közepén

Figure 2. Comparison between mid-May (laying period; left panel) and mid-June 2021 (hatching period; right panel) of a subset of a colony of Squacco Herons, showing the impossibility of relocating nests due to vegetation overgrowth on drone imagery

2. ábra A selyemgém kolónia egy részének május közepén (a tojásrakás időszaka; bal oldali panel) és június közepén (kelési időszak; jobb oldali panel) végzett összehasonlítása azt mutatja, hogy a drónok képén a növényzet túlnövekedése miatt nem lehet azonosítani a fészkeket

from the colony, in order to minimize disturbance to birds. The drone reached the vertical point of the colony (where nest attendance was registered) following a lawn-mower flight pattern, flying 70 m AGL. Then, the drone was slowly driven to an altitude of 15 m AGL, allowing for incubating birds to be clearly detected upon post-processing *(Figure 2)* and it slowly flew over the colony at a speed of 2–5 km/h. During each drone flight, an assistant researcher observed the colony from afar to exclude possible predation of unattended clutches and/or chicks by possible predators.

Disturbance was calculated as a function of the number of incubating birds flew away during the surveys because of census activities (i.e. birds moving/flying away after showing alert behavior) (Valle & Scarton 2022).

Figure 3. Nests of Squacco Heron in a mixed-species heronry (Po Delta, NE Italy in 2021)
3. ábra A selyemgém fészkek egy vegyes fajösszetételű gémtelepen a Pó-deltában (Észak-Olaszország) 2021-ben

Image Processing

In the post-processing phase, individual nests were assigned a number and counts were performed by two observers on a personal computer using DotDotGoose's count tool v. 1.3.0 (https://biodiversityinformatics.amnh.org/open_source/dotdotgoose/) on images directly

Figure 4. Drone view of a juvenile Squacco Heron perching on a shrub in a mixed-species heronry (Po Delta, NE Italy in late June 2021.)
4. ábra Drónos felvétel egy vegyes fajösszetételű gémtelepen bokron álló fiatal selyemgémről (Pó-delta, Észak-Olaszország 2021 június vége)

shot in the field or selected frames obtained from videos automatically stitched together using ICE (Microsoft's Image Composite Editor, release 2.0; www.microsoft. com); a grid was overlaid on all images and we performed a systematic counts of nests, grid cell-by-grid cell (Valle 2022).

Statistics

Categorical data are presented as percentages. Whereas we calculated the agreement between counts of nests by eye from embankments and on drone imagery, using the latter as ground truth, we did not try to compare the two methods for assessing either hatching or fledging success, due to problems of vegetation overgrowth (Valle & Scarton 2018).

Results

At the beginning of the breeding season, 46 and 12 nests were detected using drone and by eye from the embankment, respectively *(Figures 1, 2)*. These findings allow to ascribe a poor detection rate (agreement: 26%) to traditional counts of the species. Counts by eye found only the shrub nests located over the higher edge of reeds, whereas the remaining were concealed by dense vegetation that precluded their identification by observers.

Early in the season, both "high" (on shrub branches) and "low" (within reeds) nests are visible in the drone image *(Figure 2)*.

After four weeks (estimated hatching period, Heron Conservation 2022), only ten nests were relocated (among which in one case two chicks were visible), due to vegetation overgrowth *(Figure 2, 3)*. All relocated nests were placed directly either within the reed bed or on lower branches of shrubs, but always without higher branches obstructing the view from above.

Finally, in the fledging period, no nest was relocated due to further vegetation growth (sensitivity was 0%), but 27 juveniles were found, most perching on the canopy, except for two which were seen among reeds *(Figure 4)*.

As an aside, we mention that among the five more Ardeidae species, which bred in the study area, colony detectability markedly decreased across the breeding period for all the species, though at a variable extent among species, except for Purple Herons, which kept being easily detectable.

Disturbance due to drone surveys was negligible, birds being apparently unaffected by the overflying drone, though latent effects cannot be excluded. Nonetheless, no birds flew away during close-up drone inspections.

Discussion

The main result of our work is that drone monitoring allows accurate nest counts of an elusive species such as the Squacco Heron. Accuracy of counts is critical for population studies, since excess estimates may delay needed conservation actions, while in contrast, underestimation may divert resources from other truly endangered species (Thompson 2002). In the present study, drone use provided reliable counts of nesting Squacco Heron, showing a severe underestimation provided by eye counts from the nearest embankment. On the contrary, drone surveys failed to accurately assess both hatching and fledging success of Squacco Herons due to vegetation overgrowth.

Derived accurate counts of nests in our colony allowed to adjust the population estimate to more than triple the number of pairs previously thought to be present in the whole Po Delta in 2021: from 14–19 pairs (estimated using traditional methods) to 50–57 pairs (this work). This is in accordance with previous studies reporting an increase of similar magnitude in the breeding population of Purple Herons using drone rather than ground surveys (Verza *et al.* 2021, Valle & Scarton 2022).

The fact that almost four times (46 vs. 12) more nests were detected when conducting our drone surveys clearly indicates a strong underestimation due to byeye monitoring from vantage points. This finding is in agreement with those of Barbraud *et al.* (2004), who showed that a relevant underestimation (from 33 to 50%) can occur if only one observer counts nests, without taking into account the detection probability, which could be due to a number of factors: i) the low nest detection probability for this species (Barbraud *et al.* 2004), which is worsened by its asynchronous nesting period (Hafner 1978, Delord *et al.* 2003); ii) the necessity to limit the disturbance in the nesting areas, which are frequently difficult to access; and iii) the habit of the species to build small nests at little height from the ground or from the water in thickly vegetated areas. These factors make the accurate assessment of the nesting population of Squacco Heron in a colony complex, leading to nest miscount and a consequent population underestimation (Hafner 1978). Nevertheless, serial measurement of a species' breeding population is an inescapable tool for understanding its trend, which in turn is a prerequisite for implementing conservation measures, if and when needed (Carter *et al.* 2000, Thompson 2002). Drone surveys can overcome this problem. The introduction of low cost drones in the market equipped with good quality optics of small size allows entering the colonies with minimal disturbance, if any (Sardà-Palomera *et al.* 2017, Valle & Scarton 2022). A drone with these characteristics, even in low altitude surveys aimed to increase individual detectability (Corregidor-Castro *et al.* 2021), flying at low pace (10 km/h), without stopping and hovering at a precise point is often tolerated without obvious reactions from Squacco Herons, but also from the coexisting species.

In recent years, evidence on the superiority of drone monitoring in terms of accuracy and precision for counting breeding waterbirds has been numerous and nearly unequivocal. Gulls, terns, flamingos, and grebes were reported to have been counted faster and frequently better in term of accuracy and precision using drones in comparison to traditional ground counts (Hodgson *et al.* 2018, Lachman *et al.* 2020, McKellar *et al.* 2021, Valle 2022.). More controversial is the question when considering sites where vegetation occludes nests causing low detection probabilities on UAV (unoccupied aerial vehicles)-derived photographic surveys (but also on by eye monitoring). This particularly applies to herons, and more generally to Pelecaniformes, in relation to the frequent high vegetation cover of the sites usually selected by these species for nesting. Our data showed that drones are inaccurate for counting heron nests in highly vegetated habitat even when vegetation overgrowth occurs after nest location early in the season, due to obstruction of the view from above. These findings add weight to previous research, which showed that vegetation overgrowth impairs an effective use of drones in the study of the breeding biology of waterbirds (Barr *et al.* 2018). Recently, detection rates for Purple Herons nesting on reed beds using drones were reported decreasing (even if slightly) across the season, due to vegetation overgrowth, which prevents nest from being visualized (Valle & Scarton 2018).

Disturbance to breeders in response to drone intruding in colonies is a highly debated topic (Burger & Gochfeld 2009, Mulero-Pàzmàny *et al.* 2017). Colonial waterbirds were reported to abandon colonies under high disturbance pressures. In particular, a catastrophic, massive nest desertion has reported for a large (1,500 pairs) colony of Elegant Terns *(Thalasseus elegans)* after a drone crash in the colony area (www.audubon.org). In addition, in other breeding area a scarce tolerance to drone surveys was reported for Great White Egrets (Collins *et al.* 2019). At the best of our knowledge, there are no data on tolerance of Squacco Heron to drone intrusion in the colony. The absence of obvious signs of disturbance to breeders in the present study is congruent with what was previously found in our area for drones flying at elevations above ground level larger than flight initiation distances known for many species of herons (Valle & Scarton 2018). In particular, we found that many species of Pelecaniformes are highly tolerant to drone surveys in the wetland complex Lagoon of Venice – Po Delta, including herons *(Ardea cinerea, Ardea alba, Ardea purpurea, Bubulcus* *ibis, Egretta garzetta)*, Eurasian Spoonbill *(Platalea leucorodia)*, and ibises *(Plegadis falcinellus, Threskiornis aethiopicus)* (Valle & Scarton 2018, Valle & Scarton 2019b, Valle *et al.* 2021).

Our study declares a number of limitations. The main limitation is the lack of a ground inspection of the study colony to be used as ground truth. Nevertheless, we chose to restrict surveys to drones in order to avoid disturbance in a large, crowded heronry, where ground intrusions would have caused unbearable disturbance. This also explains a second limitation, residing in the impossibility of excluding settlement of late nesters as well as nest abandonment by identified breeders, when vegetation overgrowth obstructed the view from above, late in the season.

In conclusion, a drone-based monitoring greatly improves counting accuracy of breeding Squacco Herons, but fails to assess productivity, due to later vegetation overgrowth. What matters most is the possibility of collecting accurate count data early in the season using drones, without apparent disturbance to the breeders.

Acknowledgements

The work was financed by the authors. The drone flights complied with the laws in force at the time of the study, which did not require of a specific license for drones lighter than 2 kg. We appreciate the time and effort of the Editor and of the Referees and believe that addressing and accepting all their suggested revisions has enhanced the quality of our manuscript.

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