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RESEARCH

The usefulness of unmanned aerial vehicles (UAV) in white stork censusing

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Abstract

Unmanned aerial vehicles (UAV) are effective and often noninvasive tools successfully used in bird monitoring. However, when handling long-term data in the context of population changes, the consistency of methods over time is essential as the method-related bias may lead to wrong conclusions. In two distinct populations of white stork *Ciconia ciconia,* in Poland and Spain, we compared two censusing methods: traditional observation by a human from the ground and using UAV. We recorded the number of recorded fledglings, the time needed to obtain this information, and the number of detected breeding pairs in colonies. We investigated 57 and 117 nests in Poland and Spain, respectively. In Poland and Spain, the number of fledglings was significantly lower when recorded by human observer than by UAV, i.e., 2.21 vs. 2.60 and 1.35 vs. 1.55. The probability of mistakenly recording the number of fledglings by the observer was significantly lower in colonial white storks in Spain than in solitary nesting in Poland. The mean time needed to record the number of fledglings was significantly longer when using a UAV than by a human observer in both populations. The mean number of detected nests in colonies in Spain differed significantly between the human observer and UAV, 13.1 vs. 7.4, respectively. The difference between human and UAV in recorded pairs was higher when colonies were on trees than on human-made structures. We conclude that introducing UAVs in long-term studies may affect the results and should be performed cautiously.

Keywords *Ciconia ciconia* · Long-term monitoring · Colonial breeding · Waterbirds · Farmland birds

Introduction

As many bird species are considered good bioindicators (Canterbury et al. 2000; O'Connell et al. 2000; Butchart et al. 2004; Schulze et al. 2004), their long-term population monitoring brings vital information on the effects of global environmental changes, including climate change (Butchart et al. 2004; Virkkala and Lehikoinen 2014; Stephens et al. 2016; Bowler et al. 2019). Long-time series on bird distribution and abundance allow us to predict changes in many species ranges in the future (Doswald et al. 2009; Soultan et al. 2022) or even reproduce them to the past (Thorup et al. 2021). However, there are some limitations when detailed data on density and productivity are unavailable (Van Doren 2022), highlighting the importance of detailed long-term monitoring with consistent, standardised methodology. Although bird monitoring is now well established in many countries of the Northern Hemisphere, very long-term data on species distribution, abundance, and productivity are scarce. Only a few bird species are monitored on a broad geographical scale using a standardised methodology (Perrins et al. 1991). Among these species is the white stork *Ciconia ciconia*, which has been monitored in some locations for over 100 years (Bairlein 1991). More importantly, the monitoring is being performed on the entire breeding range under the International White Storks Censuses according to standardised methodology, which enables the assessment of current trends on broad

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time and geographical scales (Wuczyński et al. 2021). The white stork is an example of an easily recognisable species that does not demand high expertise during censusing, its monitoring can be performed even by amateurs, and the observer bias is believed to be low. However, in some cases recording the exact number of fledglings is difficult even for experienced observers, mainly when the nest is large, brood is numerous, and some fledglings are lying in the middle of the nest. The white stork breeding is very synchronised, and there is a short time window of 1–2 weeks when all necessary data can be collected (Aguirre and Vergara 2009), i.e., when nestlings are not able to fly but developed enough to be considered as fledglings. However, detailed censusing of breeding populations on a large scale is time-consuming and needs a lot of human resources.

A promising solution for bird monitoring is unmanned aerial vehicles (UAV) or unmanned aircraft systems (UAS), which have been used in many environmental studies (reviewed by Nowak et al. 2018). Also, in ornithology, using UAV is beneficial when access to breeding colonies is restricted due to natural barriers like water, marshland, or mountains (Nowak et al. 2018). Using a UAV might be a reasonable solution to deal with fieldwork constraints and save time for data collection. In the case of the white stork, such a method has no significant behavioural effect on breeding individuals and their offspring (Zbyryt et al. 2020), contrasting to some colonial waterbirds or raptors and vultures who react intensively and change their behaviour and time budget (Brisson-Curadeau et al. 2017; Zink et al. 2023). Moreover, the efficiency of data collecting may differ between species and populations nesting solitary and in colonies. In theory, when visiting a colony, the time needed to record nest occupancy per bird pair may be shorter than in the case of solitary breeding birds. Hence, using UAVs might be more effective for monitoring colonial birds than territorial ones.

However, in long-term studies, more than efficiency, the consistency of used methods is crucial. To maintain the constant, standardised conditions of observation, the evidence of whether the new methods affect obtained results is highly needed. Therefore, in this study, we aim to test whether results obtained via the standard observation method by a human observer from the ground differ from data gathered using UAV in terms of (i) the number of detected fledglings, (ii) time devoted to obtaining results, (iii) the number of detected breeding pairs in colonies, and (iv) if the differences in obtained results are related to the type of breeding (colonial vs. solitary) and structures supporting nests. We present the tests within two populations of white storks differing in breeding ecology, i.e., solitary vs. colonial nesting, in Poland and Spain.

Methods

Study areas and fieldwork

We conducted the study in two distinct populations of the white stork differing in ecology and facing different environmental conditions. First was near the town of Augustów in NE Poland (N 53.85, E 22.98), where the population density is high; namely 44 breeding pairs/100 km^2, and the landscape is composed of traditionally managed agricultural lands with a mosaic of grasslands (meadows and pastures), arable fields, and woods. White storks breed here solitary, sometimes forming small aggregations but not colonies. Nests are located predominantly on human-made structures like electricity posts, chimneys, and roofs of buildings, rarely on trees (Zbyryt et al. 2014), which is similar to other local populations in this part of Europe (Tobolka et al. 2013; Gyalus et al. 2018; Bialas et al. 2020). The second was in the province of Madrid in Central Spain (N 40.42, W 3.70), where the white stork population has increased and reached the density of 28 breeding pairs/100 km^2. It forms colonies of even over 100 pairs and inhabits semi-natural agricultural environments composed of pastures and agro-forestry lands, but it also uses landfill extensively for foraging. Stork colonies are located equally on trees or human-made structures: posts, pylons, or buildings (López-García et al. 2021; López-García and Aguirre 2023).

We performed white stork nests census according to the standard methodology used in white stork monitoring, which constitutes counting juvenile storks standing on the nest that are not able to fly yet, but developed enough to be considered fledglings (Wuczyński et al. 2021). This method is assumed reliable and not observer-biased, particularly when performed by experienced observers. To test this assumption, in 2017 and 2018, in 297 white stork nests in Poland, we conducted a survey according to the standard methodology by two observers, and in 2019 in 37 nests by three independent observers. Repeated-measures analysis of variance revealed no significant differences between observers in the number of recorded fledglings (in both cases, $p > 0.19$).

In 2019 (between 1st and 2nd July), we surveyed 57 white stork nests in NE Poland. One experienced observer who knew well the study area (AZ—co-author of this paper) recorded the number of fledglings using binoculars 10 × 42. We conducted observation until we were convinced that all chicks were detected. In parallel, the UAV operator performed a flight aiming to record the number of fledglings from 30 m above the ground while the nest height was between 10 and 12 m. We also recorded the time needed to obtain breeding output (the number of fledglings) starting from when the observer/UAV operator got off the car to record the number of fledglings and returned to the car (the observer and UAV operator separately). Using a GPS receiver, we also measured the distance between the observer and the observed nest. In 2021 (between the 29th of May and the 12th of June), we performed a survey in central Spain, Madrid District (by ALG & RGM—co-authors of this paper) similarly. The white stork breeds here colonially; hence, the method was adjusted to local conditions, i.e., the time was recorded for the whole colony survey and divided by the number of nests in the colony. If possible (mainly when nests were on buildings), the observations were conducted from a greater distance to avoid disturbance of the breeders in the colony, as colonial, white storks are much timider than solitary ones inhabiting human settlements. We surveyed 117 nests aggregated in 15 colonies and one solitary nest. Similarly to the fieldwork in Poland, we took full-resolution images at a height of 30 m. We analysed recordings obtained by UAV after the fieldwork and included the time needed for the image processing into the time of UAV observation. Colonial breeding of the white stork in Spain also allowed us to test differences in the number of recorded nests between traditional observation from the ground by a human observer and the UAV. We used DJI Mavic Pro Zoom with a 12MP camera and a 24-mm equivalent lens, rendering images with a GSD of 0.95–2.00 cm/pixel. The flights were automated using the DJI Pilot app.

Statistical analyses

We used the two-way repeated-measures analysis of variance (ANOVA) to test the effect of nesting type (solitary *vs* colonial), the within effect of observation method (UAV *vs* human observer), and interaction (nest type × observation method) on the number of detected fledglings and time needed for the inspection of white stork nests.

Moreover, we used logistic regression to test the probability of making mistake when recording the number of fledglings by a human observer in stork colonies in Spain and solitary nests in Poland. We coded 0 when human observed a different number of fledglings (always lower) compared to UAV and 1 when human observed the same number as UAV.

We used *U* Mann–Whitney paired test to compare the number of detected breeding pairs in colonies in Spain between the human observer and UAV. Also, with the Mann–Whitney test, we tested whether the difference in recorded pairs (always equal or higher by the human observer than UAV) was related to nest-supporting structures grouped into two categories: trees vs. anthropogenic structures (buildings and posts).

Results

In solitary nests in Poland, the mean number of fledglings recorded in the nest by the human observer was 2.21 while by UAV-2.60, while in colonially nesting storks in Spain respectively 1.35 and 1.55, and the method was significant factor differences in variance ($F_{1,173} = 32.28$, $p < 0.001$) (Fig. 1d).

The mean time needed to record the number of fledglings in Poland was 29 and 127 s (observer and UAV, respectively), while in Spain-59 and 322 s. Differences were method-related ($F_{1,72} = 485.6$, $p < 0.001$, Fig. 1b).

The between-subject tests of the effect of nesting type (solitary *vs* colonial) were also significant in the number of detected fledglings ($F_{1,173} = 30.12$, $p < 0.0001$, Fig. 1c) and in the time needed for the white stork nest inspection ($F_{1,172} = 43.41$, $p < 0.0001$, Fig. 1a). The within-subject tests indicate that the interaction of observation method and nesting type was significant in the number of detected fledglings ($F_{1,173} = 3.91$, $p = 0.049$), whereas in the time needed for the white stork nest inspection was not significant ($F_{1,173} = 0.63$, $p = 0.430$).

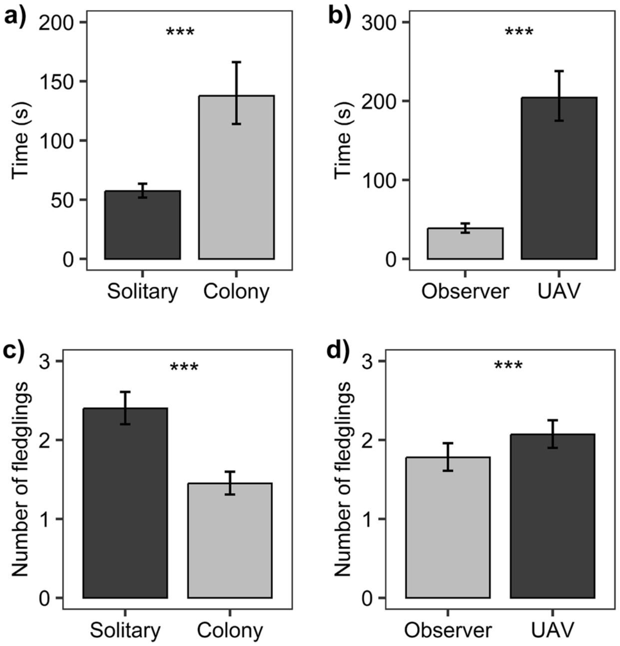

Fig. 1 Comparisons of **a** time needed by UAV to record the number of fledglings in solitary nesting storks in Poland and colonially nesting in Spain, **b** time needed to record number of nestlings by human observer from the ground level and the UAV in both study areas, **c** number of fledgling recorded in solitary nests and in colonies, and **d** number of nestling recorded by the human observer and UAV in both areas. Whiskers present standard error. Differences are statistically significant (in all cases, $p < 0.001$)

Also, the number of detected nests differed significantly between the human observer and UAV, i.e., 13.1 and 7.4, respectively (Mann–Whitney *U* test, $p = 0.006$). However, the difference in the number of recorded nests was related to the type of nest substrates. In colonies located on trees, the error was significantly higher (on average 7.7, range: 0–24 detected pairs) than in colonies located on human-made structures like buildings and posts (no differences in the number of detected pairs, Mann–Whitney *U* test, $p = 0.015$).

The probability of dependent mistakes by the human observer significantly differed between solitary and colony nesting ($F_{1,173} = 7.07$, $p = 0.009$, Fig. 2).

Discussion

In this study, the numbers of recorded white stork fledglings by human observers were significantly lower than when using UAVs. Although it is not surprising, as the access to a nest for humans watching from the ground level is more constrained than for a flying object recording from above, so far, the method of counting stork fledglings was assumed precise enough even when amateurs performed the survey. Thus, it has been used long term and worldwide (Wuczyński et al. 2021). Results of our simple experiment bring essential information that during the long-term censusing of the white stork population, the overall breeding output may be underestimated when only ground checking is performed. The simplest explanation is that when the observer is counting fledglings that are standing on the nest, some of them can sit or lay in the middle or on the side of the nest, invisible to the observer, particularly in cases when the nest is large (Vergara et al. 2010; Zbyryt et al. 2021). Similar results were obtained in the study on a waterbird, the whooper swan *Cygnus cygnus*. The number of recorded cygnets was significantly higher when using UAS than by human observer. The same was true for the number of successful broods *vs* breeding failures (Sikora and Marchowski 2023). The case of the swan is more evident as this species inhabits less accessible environments than storks. Moreover, in our study, the probability of making a mistake by the human observer was lower when storks were nesting in colonies than solitarily. It is probably due to the different conditions of observation angles in these two populations and nesting types. Solitary nests in Poland are mainly located inside villages, within the settlements on electricity poles, chimneys, or roofs (Tobolka et al. 2013), so it is sometimes difficult to observe them from a further distance, outside the village, due to rural settlements surrounding the nest constraining the observation. Colonies in Spain are often on tree aggregations far from the settlements. Due to the timid behaviour of nestlings storks, the best way to observe them is from a distance, which makes the observation angle more convenient to record the exact number of fledglings, including those sitting or lying in the nest.

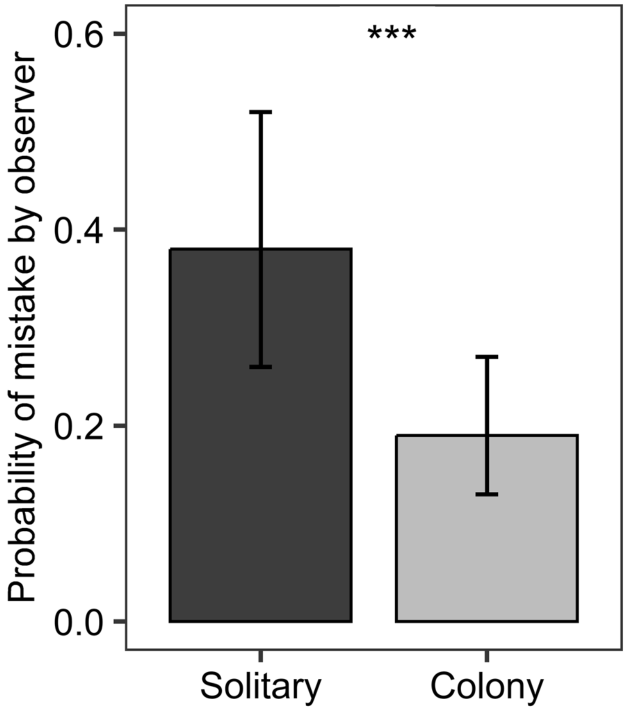

Fig. 2 Comparison of the probability of making a mistake by a human observer and UAV in recording the number of fledglings in colonial nesting in Spain and solitary nesting white storks in Poland. Differences are statistically significant ($p < 0.009$)

On the other hand, when performing long-term monitoring on the same study site, an additional interview with property holders where the nest is located is a standard protocol, particularly when brood fails (Janiszewski et al. 2013; Tobolka et al. 2015). Thus, the obtained results can be supplemented and more accurate than those base on simple observation. However, UAVs may be used as a supplementation when the observer cannot see how many fledglings are in the nest or cannot gather supplementary information from the local inhabitants. Moreover, long-term monitoring is often accompanied by chick ringing, which demands direct visits in nests. Hence, data on the number of fledglings collected on the long-term study sites can be considered more accurate than those obtained in our field experiment and those collected during international white stork censuses.

The time needed to obtain information about the number of fledglings differed significantly between the human observer and the UAV in both study sites, Poland and Spain, which contradicts other studies. In a survey of oystercatcher *Haematopus ostralegus*, the traditional censusing method was significantly less precise, more time-consuming and, therefore, more costly than UAV (Valle and Scarton 2019). However, our study design does not give information on how much time is needed to record the exact number of fledglings by a human observer standing on the ground. This might be done by a different experimental approach when the valid number of fledglings is recorded from above first. Then, the time needed for recording the same number of fledglings by a human observer is noted. Such an approach would allow us to test if there is a difference in time to obtain the same results by these two methods. Moreover, it would also give us information on how much time is needed to record the maximum number of fledglings.

Using the data from Spain, where white storks breed mainly in colonies, the recorded colony size was significantly larger when surveyed by the human observer than by UAV. It contrasts with the study on the ground-nesting bird, the black-headed gull *Chroicocephalus ridibundus*, where images obtained from an unmanned aircraft system (UAS) allowed to establish colony size with very high precision (Sarda-Palomera et al. 2012) and research on oystercatcher, where a higher number of occupied nests was detected using UAS than by traditional census method (Valle and Scarton 2019). In the case of the white stork, the differences in the assessment were due to the tree canopies covering some nests, which affected the numbers obtained by UAVs. This limitation can be avoided by using a thermal infrared camera that has proven effective in at least mammalian studies (Linchant et al. 2015). However, such a method has several limitations, e.g., high costs of the device, the lower resolution of images, and the specific time of the survey, as the temperature of the background has to be lower than the object of interest, which is usually early in the morning or at night. The lower resolution of the infrared camera demands a shorter distance to the observed object, which in turn may cause a disturbance, particularly in colonially nesting storks.

Although the use of UAVs may be disputable in terms of methodological consistency in long-term censuses, it may be helpful for other purposes, like monitoring the clutch size (number of laid eggs), hatching success, or hatchling survival. As white stork nests are greatly inaccessible for observers without special equipment, e.g., cherry-picker or ladder, the use of UAVs allows collecting such information without direct visits in nests, reducing the costs and time needed to obtain such data. However, for some species, closer interactions between UAV and breeding individuals may have negative consequences, e.g., collisions, increased stress or change in behaviour (Junda et al. 2016; Weston et al. 2020), which can affect significantly breeding performance, particularly in sensitive species like raptors or vultures (Zink et al. 2023). Moreover, as most bird species in Europe are protected by law, all activities causing bird disturbances need local conservation authorities' permission. Another limitation of using UAVs is additional permits when flying close to settlements, electricity networks, airports, or military training areas. Thus, this method cannot be used universally.

Conclusions

In the case of the white stork, we cannot certainly claim that the use of UAVs may save the time and costs of the survey. It may increase the accuracy of collected data. However, it may also cause method-based bias.

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Author contribution MT wrote the main manuscript draft. MT and LD analysed the data and prepared figures. AJG, JIA, RGM, AZ carried out the fieldwork. All authors contributed in the conceptualisation of the study and reviewed the manuscript.

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Data availability Data available after request.

Declarations

Conflict of interest The authors declare no conflict of interests.

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