# USAGE OF DRONES IN ASSESSING BIRD NUMBERS ALONG THE EAST ATLANTIC FLYWAY

Scientific Report from DCE – Danish Centre for Environment and Energy no. 619 2024

AARHUS UNIVERSITY
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# Data sheet


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Abstract: This report originates from a project entitled "Innovation for Migratory Bird Monitoring along the East Atlantic Flyway," funded by the European Commission's Structural Reform Support Programme. Traditional methods for monitoring breeding and staging waterbirds face challenges such as risk of disturbance and uncertainty about the precision of counts associated with the use of human observers, which has prompted the development of new drone-based remote methods for counting and mapping waterbirds. This report compiles experiences from attempts to monitor a range of waterbirds at different points in the annual cycle using drones. It is now evident that drones are very useful when monitoring species breeding in colonies, e.g. spoonbills, gulls and terns. Ongoing studies are still exploring the pros and cons of drone-based monitoring of cryptic species and non-colonial species of breeding waterbirds. Monitoring of waterbirds outside the breeding season with drones is often far more challenging due to their wider distribution in the landscape. Some intertidal feeding species are also highly sensitive to approaching drones, especially when roosting at high tide. There is limited experience in monitoring birds foraging on sand- and mudflats at low tide. Further research is required to identify the precise circumstances under which drones are likely to greatly improve the quality of monitoring of waterbirds during and outside the breeding season.



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# Contents

# Summary

The monitoring of East Atlantic Flyway breeding and migratory waterbirds for management purposes has been vital and ongoing for many years. Traditional methods using human observers pose challenges under certain conditions. For example, sites may be difficult or impossible to access, birds may gather in large numbers where count precision and accuracy affect results or where the risk of disturbing the birds is high. This has prompted interest in exploring the potential to apply new drone-based methods for counting and mapping avian abundance and distributions. The use of such techniques offers gains in accuracy and efficiency and often allow surveys in areas previously physically inaccessible to observers.

The experience of mapping and monitoring of breeding birds using systematic transect flights has been shown to be successful, especially for colony breeders such as spoonbills, cormorants, gulls and terns that were previously monitored by other methods along the East Atlantic Flyway. Ongoing studies are also exploring whether drones can assist with monitoring breeding waterbirds that are cryptic and/or breed more dispersed.

Monitoring roosting birds in intertidal environments with drones has proved to be more complex due to their dispersed nature and susceptibility to disturbance. There is limited experience in monitoring birds at low tide, which also face many practical challenges. Birds feeding in the intertidal do so over vast areas, shift constantly in relations to water levels and food abundance and as concentrated at high tide become restless and unpredictable. Legal restrictions on drone-flying also restrict their utility in some areas. Despite this, drones offer the possibility of supplementing traditional surveillance techniques in areas impossible to access or where birds are difficult to count conventionally or where ground visits incur unacceptable levels of disturbance.

Using human observers to count birds on drone-acquired imagery remains common but labour-intensive. Automation of wildlife detection in drone imagery is emerging as a faster, more precise and reproducible alternative in the future, but requires datasets for algorithm to facilitate automatic image processing.

We conclude that drone-based methods offer new possibilities for highly accurate and effective counting and mapping of waterbirds, especially in the breeding season and in particular for ground-nesting colonial species. Recent results suggest that drones with thermal and zoom cameras can be effective monitoring cryptic species showing dispersed nesting in the landscape. Drone applications therefore not only enhance accuracy and efficiency but enable survey of areas posing logistical problems.

Training of drone operators is essential to ensure accurate monitoring and minimise the risk of disturbance.

While drones show promise as monitoring tools for waterbirds, best-practice protocols need to be established to avoid or minimize disturbance, especially in protected areas. Further research is needed to optimize monitoring methods and enhance data analysis.

# 1 Foreword

This report collates information about the applicability of drones to monitoring of waterbirds both during and outside of the breeding season, requested by Sovon, Dutch centre of Field Ornithology as part of the project 'Innovations for Migratory Bird Monitoring Along the East Atlantic Flyway' (FLYWAY). This project is coordinated by the Coastal & Marine Union (EUCC) and financed by the Technical Support Instrument (TSI) under the European Commission's Directorate General for Structural Reform Support (DG REFORM). The project was commissioned by the Dutch Ministry of Agriculture, Nature and Food Quality also on behalf of its counterparts in Germany and Denmark.

To provide a comprehensive view, Sovon commissioned Aarhus University to review the opportunities and challenges associated with using drones to monitor and study bird populations along the East Atlantic Flyway (and within the Wadden Sea itself). The present report largely benefits from the results of two dedicated workshops, of which one was held in Groningen in March 2018, and another was held in Hamburg in February 2023 (see Appendix I). These workshops were organised by the Expert Group on Birds under the Trilateral Monitoring and Assessment Program (TMAP). This group facilitates the trilateral cooperation between the Netherlands, Germany and Denmark in the international Wadden Sea. The use of drones has also been discussed in the trilateral TMAP monitoring programme, notably in relation to surveying breeding birds. Within this context, it is also relevant to consider the development of common guidelines for application and data processing, in order to harmonise the use of drones for monitoring within the Wadden Sea as much as possible.

The report was prepared by DCE - National Centre for Environment and Energy, Aarhus University, with input from Tidal Consult and Sovon. Tidal Consult contributed an initial draft of the report and Sovon provided clarifications on the content, particularly in the Background and Introduction chapters.

# 2 Introduction

There has been a tradition of coordinating international monitoring of breeding and migratory waterbirds along the East Atlantic Flyway for many years. In the Wadden Sea, a coordinated survey scheme (Trilateral Monitoring and Assessment Program, TMAP) was established in the late 1980s. Stronger cooperation amongst states along the various African-Eurasian Flyways has been directed towards developing a more integrated waterbird monitoring programme since 2009, initiated by the so-called Wadden Sea Flyway Initiative (van Roomen et. al. 2022). The vast amounts of monitoring data, describing the number and occurrence of bird species in time and space, have been used for a wide range of purposes both in relation to generating population trends, underpinning nature conservation management, for instance in supporting the designations of protected areas in relation to individual countries or at the flyway level. Within the Trilateral Wadden Sea Cooperation agreement, it informs nature conservational managers and policies through the cycle of Quality Status Report generation (https://qsr.waddensea-worldheritage.org/).

The FLYWAY project places emphasis on gaining a comprehensive understanding of potential avenues for innovation in our monitoring of waterbird populations. A notable example is the utilization of drones (sometimes also called Unmanned Aerial Vehicles, UAV) that have emerged as powerful and exciting potential tools for wildlife monitoring and research in the past decade, which undoubtedly offer much presently unrealised potential. In the context of avian monitoring in the East Atlantic Flyway, the following applications are particularly relevant:

1. Determining the abundance of breeding waterbird populations, concentrating on colonial as well as dispersed breeding species, especially when in situations with low detection probabilities or difficult habitats, where conventional surveys may be inaccurate, require extra manpower and/or come with undesirable levels of disturbance.

2. Estimating waterbird numbers present at stop-over and wintering sites, with a specific focus on intertidally feeding species present at high tide roosts. This also includes communal roosts of species like waders, gulls, terns, geese and cormorants, both on land and open waters.

3. Determining the foraging abundance and distribution of waterbird species, especially when dispersed on tidal mudflats during low tide, when the maximum foraging habitat is available.

Traditional monitoring of colony-breeding birds has often been carried out by counting assumed occupied nests or by counting the individuals present at the site of the colony (see Hälterlein *et al*. 1995 for guidelines in the Wadden Sea). However, when moving close to or within a bird colony, observers inevitably cause unintentional disturbance, affecting both the monitored species and often other species of breeding birds as well. Even though the loss of eggs due to such disturbance tends to be low, such disturbances can reduce the birds' breeding success (Carney & Sydeman 1999).

To minimize the risks from unintended disturbance, bird colonies have been largely counted from a distance, usually from one or more observation points.

This method, however, does carry a high risk of yielding inaccurate totals, often significantly underestimating the actual total number of individuals (Holm & Bregnballe 2019). Furthermore, the results obtained from this method often vary depending on the experience of the individual bird counter (Hellwig 2009; Koffijberg & Dijksen 2007; Laursen *et al*. 2008). In this context, use of drones could improve the accuracy of the counts, but also help to produce a more reproducible and thus more standardised result, which is essential in long-term monitoring systems.

Counting migratory birds at many of their critical resting and foraging areas can also be challenging. Resting waterbirds, especially waders, gather in large, dense flocks, which can be very hard to count by observers standing on the ground and looking peripherally into the flock through a telescope. The birds in the front can often obstruct those in the back, and many individuals can easily be missed when the birds rest in areas with vegetation or uneven terrain (Castenschiold *et al.* 2022, 2023). This uncertainty presents a series of well-known challenges to accurately counting large numbers of resting waterbirds conducted not just in the Wadden Sea, but on many other wetlands globally, where migratory birds are counted throughout most of the year.

The risk of disturbance by observers and inaccurate data from counts affected by the potential differences in bias and error of individual observers has highlighted the potential advantage of developing new methods for counting and mapping the distribution of both breeding and roosting birds. In this report, we provide an overview of the experiences so far available in the literature and from our own experiences with the use of drones for monitoring and data collection. As well as demonstrating the advantages, we also provide evidence to show situations where the use of drones is less useful or causes too much disturbance. These results are presented based on the review of numerous papers and reports that have been published in the past decade and on the results of our own interviews with key-players in the field, assisting us to come up with recommendations about the possibilities and impossibilities of using drones to generate cost-effective, robust accurate data on waterbird distribution and abundance.

In conclusion, we evaluate where drones prove most beneficial in bird monitoring along the East Atlantic Flyway and discuss the current and future challenges we face.

# 3 Methods, hardware and software

## 3.1 Types of drones and their advantages and disadvantages

To date, two main types of drones have been used for bird monitoring: multirotor drones and fixed-wing drones. Contemporary customer grade drones consist of a wide range of types, from low-budget to expensive enterprise level off-the-shelves-drones, most of which are multi-rotor and commonly designed as four propelled quadcopters. Positive experiences have been reported with various multirotor drones. For breeding birds, this includes the Mavic Pro (Holm *et al*. 2018, Rasmussen 2022), the Phantom 4 Pro (Holm & Bregnballe 2019, Castenschiold *et al*. 2022, 2023), and the Mavic 3 Zoom (Holm *et al*. 2023). For larger models the DJI Matrice 210 has been used to monitor several species of colony breeders (Holm & Bregnballe 2020). Likewise, the DJI Matrice 300 RTK for monitoring in the Wadden Sea (BioConsult SH 2023) and for nesting seabirds (Castenschiold & Hammer 2021). Similarly, good results have been achieved with fixed-wing drones like the E384 (Figure 3.1.2) (Holm & Bregnballe 2019, Corregidor-Castro *et al*. 2022) and Wingtra (BioConsult SH 2023). However, both drone types and individual models have their advantages and disadvantages.

**Figure 3.1.1.** A DJI Matrice 210 on its way to photograph a colony of Herring Gulls at Venø, Denmark. Credit: Thomas Eske Holm.

Fixed-wing drones are characterized by their long endurance and the ability to cover significant distances during flight. They exhibit higher speed, and some types necessitate a larger area for take-off and landing. In photogrammetric work this can be advantageous, when mapping larger areas. But since the camera is usually fixed, and the recorded imagery thus constrained to vertical or fixed angled photographic mapping, they are limited to this kind of survey. Notably, fixed-wing drones can be considerably more expensive than their multi-rotor counterparts.

Multirotor drones come in a variety of sizes and configurations. Smaller drone models with a width of 15-20 cm unfolded, such as the DJI Mavic series and the Autel Evo series, offer advances due to their small and portable size, which allows for easily transportation in a small bag or backpack. Moreover, in many situations they cause less visual and auditory disturbance due to their size and weight. Drawbacks associated with many smaller and budget drone models include their vulnerability to windy conditions due to their size and battery limitations and the difficulty of seeing them at a distance. Depending on the weather and cloud cover, their visibility against the sky can vary. In some cases, they might be hard to see even when only a few hundred metres away from the drone operator (which may conflict with legal requirements that necessitate flying within so-called Visual Line of Sight (VLOS) and Beyond Visual Line of Sight (BVLOS) regulations, see section 3.2.1). Therefore, based on experience, these smaller drone types are best for counting when the birds are nearby and under calm weather conditions. They can also serve as an extra pair of eyes in the sky during a traditional bird count (Holm *et al*. 2023).

Middle sized platforms with a width of 35-60 cm, such as the DJI Phantom and Inspire series and the recently released DJI Matrice 30 series have the potential in some survey settings to accommodate features and advantages from both the small models' portability and the larger drone models' customizability.

**Figure 3.1.2.** A E384 fixed-winged drone just after take-off in the Danish Wadden Sea. Credit: Thomas Eske Holm.

Often, there is a need to operate at greater distances. Here, larger and more professional drones, either multirotor or fixed-winged with a width more than 60 cm are suitable, because VLOS is greater. Drone size aids with greater visibility and allows to operate at greater distances and with higher wind speeds. However, these drones can be more disruptive in certain situations because they are more visible in the sky (Holm *et al*. 2023). For instance, fixed-winged drones can resemble predators to some bird species (Holm & Bregnballe 2019). Larger drones also often provide the flexibility to fit interchangeable and custom-made cameras and are furthermore fitted with sophisticated onboard sensors for avoidance and obstacle detection. As well as fix-winged drones, larger multirotor drones come at a considerable price, demand more operator training, and are subject to stricter regulations. Currently larger models include the DJI Inspire and Matrice series, of which the Matrice 210 and the Matrice 300 RTK offer some of the most versatile and customizable avian surveillance platforms.

Resilience towards precipitation is another factor to consider when choosing drone models. This is usually only a feature of larger high-end professional models, such as the DJI Matrice series, which should be considered when planning flights and survey activities in areas prone to periods with a high probability of rainy and misty conditions (Castenschiold & Hammer 2021).

Lastly, sound emission and auditory detection is known to vary quite profoundly between the individual drone models and species investigated (Scobie & Hugenholtz 2016, Islam *et al*. 2017). Therefore, when starting new research activities, it is highly advisable to carry out pre-survey exploratory flights with the aim of assessing the disturbance level caused by the introduction and surveying activity of a given drone model to the species being surveyed *in situ* (Islam *et al.* 2017, Jarrett *et al.* 2020).

## 3.2 Flying Methods

There are two main ways to fly drones for bird monitoring: transect flights and manual flights. Transect flights are designed to systematically map larger areas, such as islands with breeding waterbirds or colonies These flights operate along preset waypoints at a fixed and predetermined altitude, e.g., 25 metres or 40 metres, and the flight is autonomously controlled by software like DroneDeploy (2023) (Figure 3.2.1) or DJI Pilot (2023). The lower the altitude, the smaller the area covered by each image. Therefore, low altitude transects flight require longer flight times compared to higher altitude flights. However, flying at a lower altitude improves image quality, ensuring better identification of bird species and provide supplementary information of value to the observer, such as bird behaviour and posture. It is important therefore, to determine the optimal altitude in terms of image quality, risk of disturbing the birds and flight duration for a given project before starting on such a project. Obtaining data for these parameters in a flight protocol is therefore crucial prior to performing any survey (Drever *et al*. 2015, Lyons *et al*. 2019, Castenschiold *et al*. 2023).

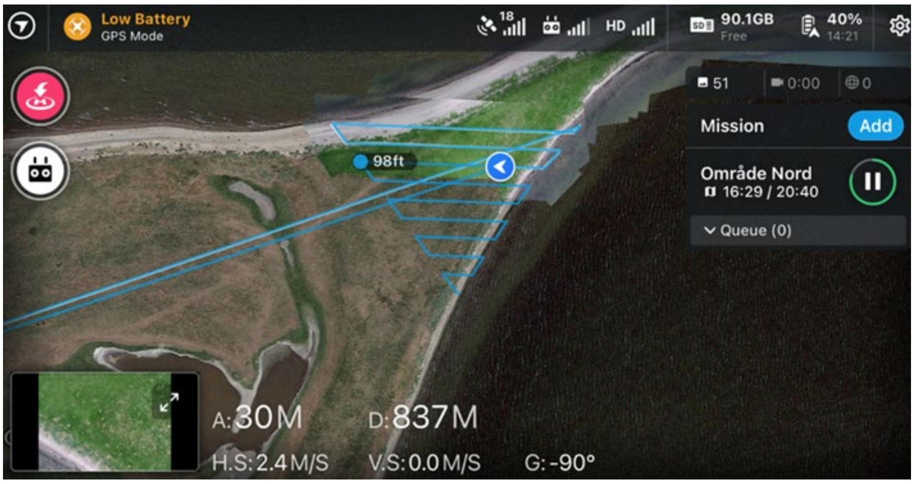



**Figure 3.2.1.** Screenshot of the drone monitor screen while mapping a Herring Gull colony using DroneDeploy. Credit: Thomas Eske Holm.

Manual flights are flights that are controlled by the pilot all the time. They are mainly used for smaller areas or mapping species whose locations cannot be predicted, e.g. nest sites of species with concealed nesting behaviour. This includes temporary islands and sandbanks where birds nest, or flocks of resting birds on the water surface. Manual flight is also utilized in areas with challenging and complex terrains, like marshes with nesting cranes, where the drone can provide a better overview (Holm & Bregnballe 2019). This method is also ideal for photographing flocks of birds on water, e.g., resting geese or swans (Holm *et al*. 2023). During manual flights, both photos and videos can be recorded throughout, collecting as much information as possible.

### 3.2.1 VLOS and BVLOS

Standard drone operations throughout most of Europe are permitted, as long as the remote pilot maintains Visual Line of Sight (VLOS) with the aircraft at all times. This means that the remote pilot must be able to clearly see the unmanned aircraft and the surrounding airspace at all times while it is airborne. The primary requirement of any flight is to avoid collisions, and VLOS operation ensures that the remote pilot can monitor the aircraft's flight path and manoeuvre it clear of potential obstacles. The disadvantage of VLOS flight is that the drone pilot cannot fly more than 500 to 2000 metres away. This places a significant limitation on the size of the areas that can be monitored with drones.

Beyond Visual Line of Sight operations (BVLOS) are generally not widely permitted and require a special permit from the relevant authorities (EASA 2024). However, the advantage of BVLOS operations is the capability to map areas that are larger or more remote, than are beyond the limitations of VLOS flight. National Drones (2023) highlighted an example of BVLOS with the ability to survey a 200 km$^2$ site in South Australia. The drone flew 1262 km in 11.5 hours with an average groundspeed of 110 km/h, producing over 8000 high-resolution images and 1TB of data in the final deliverables. This example indicates the technical feasibility of mapping larger areas with drones. The barriers to achievement in this case include obtaining the necessary permit, investing in equipment, as well as training and licensing specialists to fly the drones. Finally, processing and analysing the relatively large amounts of data generated remain significant barriers.

## 3.3 Choice of Camera

Drones come equipped with different types of cameras. Typically, they include a standard camera with a fixed lens, which is often sufficient. However, there are situations where different lenses can be advantageous. For instance, several higher-end models come with camera options, which include optical zoom setups. This feature becomes crucial, especially in areas with multiple resting bird species, where there's a significant risk of the drone causing species specific disturbance. The drone can hover at a safe distance, allowing for the identification of ducks, gulls, and other species with sufficient zoom without causing any disturbances. Zoom also enables the study of the breeding success of large birds of prey, like the White-tailed Eagle *Haliaeetus albicill* (Holm *et al*. 2023).

Using a thermal camera can also be beneficial. It can help locate birds that might be hard to spot in regular images, such as Common Snipe *Gallinago gallinago* active at night (J. F. Castenschiold, unpublished data) or Common Crane *Grus grus* (Chen *et al*. 2023). Such a camera can simultaneously capture regular and thermal images (dual sensor approach), assisting in verifying whether an object in the image is a bird. For instance, it can help identify "false positives"—objects that resemble a bird in a standard drone image but don't emit heat in a thermal image, indicating they're not living birds (Corregidor-Castro *et al*. 2021). Application of thermal sensors have a trade-off during spring and summer, as they work best in situations with largest difference between temperature of the object to search and air temperature. Hence, warm and sunny weather means that drone operations can only be carried out sufficiently in the earliest hours of the day.

## 3.4 The choice between photos and video

When conducting autonomous transect flights, one typically captures photos for subsequent stitching, thereby generating a high-resolution continuous overview of the area flown over. In contrast, during manual flights, one can choose between capturing either still photos or videos. Although it's often possible to capture both video and photos simultaneously, especially with DJI drones, this may result in lower resolution images, compromising their utility for tasks such as species identification. The decision to capture photos or videos depends on the purpose of the monitoring. In certain cases, using video may facilitate easier identification and counting of birds, a choice that should be evaluated by the drone operator on a case-by-case basis.

## 3.5 Stitching of photos

During transect flights, hundreds or even several thousand pictures are often taken for mapping purposes. These images are captured with a minimum of 65% overlap and can be uploaded to software programmes like DroneDeploy (2023), Pix4D (2023), or ArcGIS Drone2Map (2023) after the flight. These programmes can then stitch together the numerous photos, resulting in a comprehensive, high-resolution image of the surveyed area, such as a breeding island with nesting birds. The birds in the composite image can then be identified and counted manually or by using artificial intelligence. In many cases, it will be possible to distinguish between breeding and resting birds, as well as birds in standing or sitting positions. Additionally, in breeding colonies, nests and potentially eggs or chicks may be visible if the birds are not on the nest (Holm & Bregnballe 2019). When working with thermal imagery, stitching of photos may become troublesome, as algorithms to put the single images together do not work effectively.

## 3.6 Data analysis

Using drones for monitoring wild populations introduces a new challenge, namely the management of large volumes of data (from images). A significant concern for frequent drone users is how to effectively store and manage their data, because a substantial amount of data can be generated (Starnes *et al.* 2020).

While drones can assist in capturing large amounts of imagery, to convert raw images into numbers of organisms encountered, the detection process necessitates either manual evaluation of the imagery or automated object detection using machine learning algorithms. Although manual evaluation of drone-acquired imagery currently is the most commonly employed method, it can be highly demanding in terms of man-hours. In recent years, many projects have harnessed the potent combination of drones with automated or semi-automated detection of wildlife in this imagery. This can not only be significantly faster compared to manual counting and bird identification, but it also has the advantage that the data are processed in a standardised (rather than subjective, potentially observer biased) way. In some cases, it has been proven to be more accurate than relying solely on human observers (Corcoran 2021, Wirsing *et al*. 2022).

Semi-automated identification methods in data processing have been utilized for several years. Valle (2021) employed the freeware programme ImageJ to conduct fast semi-automated counts of foraging flocks of wintering Greater Flamingos. That study demonstrated that drone images provided more precise and larger numbers compared to ground counts, and the semi-automated technique was also faster and more accurate than manual counts of the drone images.

Corregidor-Castro *et al*. (2021) utilized the training sample manager tool in ArcGIS to develop a semi-automatic method for counting individuals and differentiating species. They conducted a supervised classification, creating a training set where pixels in the image were assigned to different classes. These classes were differentiated based on the unique spectral signature of the pixels, resulting in well-defined classes crucial for classification accuracy.

Corregidor-Castro & Valle (2022) also used ImageJ for the analysis and count of breeding seabirds, significantly reducing the time needed for analysis. The advantage of ImageJ lies in its freeware nature, making it accessible to users with limited resources compared to commercial software.

While Photoshop is a commercial product, it can facilitate the analysis of photos similar to ImageJ. The programme can also be useful for analysing images of large colonies of Black-headed Gull *Chroicocephalus ridibundus*. However, Photoshop has the limitation that it can only handle up to 4090 selected dots. In colonies with greater numbers, the image size needs to be constrained to contain less than 4000 birds.

In recent years, there has been a significant focus on automatic counting and identification of birds using deep learning. Such a system conducts a fully automatic preprocessing and analysis of drone images. By the human observe providing labels, such as species names, for the different birds observed in the images, the system trains a deep neural network to recognize the relevant objects. Once such a model is fully developed, the neural network can be directly applied to similar images, eliminating the need for manual selection and labelling because the system is now trained to recognize the objects (Holm *et al*. 2022b).

There are numerous examples of studies where deep learning has been successfully employed for counting and identifying birds in drone images. Hayes *et al*. (2021) developed a deep learning model that provided accurate and efficient monitoring of large seabird colonies, while Mpouziotas *et al*. (2023) created a model using automatic detection and tracking processes for effective and precise monitoring of bird populations without the time-consuming manual identification. Kellenberger *et al*. (2021) developed a model that detected and classified 21,000 birds in imagery in just 4.5 hours. However, all models need verification and validation for accuracy. Models fail to be accurate enough either because the drone images are of poor quality (e.g. taken from too far a distance) or because the project data are insufficient to effectively train the model for high accuracy object recognition (Holm *et al*. 2022b). In the future, artificial intelligence is expected to outperform manual counting and identification, at least when it comes to counting birds in larger numbers.

# 4 Legal requirements

Since 2021, the European Union Aviation Safety Agency (EASA 2024) has standardized drone regulations across its member states and a few additional European countries (UAV coach 2023a). While countries must adhere to the drone regulations established by EASA, they typically also have country-specific regulations.

In general, these regulations do not permit the use of drones beyond visual line-of-sight (BVLOS). This limitation poses challenges in expanding drone BVLOS operations for monitoring migratory birds and mapping tidal areas. BVLOS operations require drone operators to be registered by the National Aviation Authority (NAA) and obtain operational authorization from the NAA to operate within the Specific Category (EASA 2024).

Many areas that have been targeted for drone use in monitoring, particularly those designated as Natura2000 areas, will be subject to different national regulations. Military training areas, often located in crucial water bird habitats, typically exclude drone operations.

In numerous African countries, there is a lack of legal regulation for drones (UAV coach 2023b). Determining the specific rules and regulations for a particular country may be challenging. As a starting point, it is recommended to consult community-collected information available at https://www.drone-regulations.info. Engaging with local groups and potentially forming partnerships with them has proven to facilitate smoother drone deployments with reduced concerns from local communities (Duffy *et al.* 2018).

# 5 Monitoring of breeding birds

## 5.1 Disturbance

When the first drones emerged and began to become commonplace, many feared that drones would scare birds and other wildlife. This fear was not entirely unfounded. For example, low-flying drones have been recorded to frighten Peregrine Falcons *Falco peregrinus* away from their nest (Naturstyrelsen 2016) and scare herds of Red Deer *Cervus elaphus* (Kjølberg 2016).

Holm *et al*. (2018) conducted a study with the aim of determining if they could fly over colonies of, among others, breeding Black Guillemot *Cepphus grylle*, Herring Gull *Larus argentatus*, and Common Eider *Somateria mollissima* with a Phantom 4 drone, without causing the birds to fly away (Figure 5.1.1). In the experiment, the birds were observed from the drone's camera, and their reactions to the drone were recorded with binoculars or a telescope.

**Figure 5.1.1**. Study on the disturbance impact of drones on breeding herring gulls conducted by Holm *et al*. (2018). The image shows a drone flying quickly and low over a gull colony without notable reactions from the birds. Credit: Niels Kanstrup.

The birds' responses to the drone were then scored using the following internationally agreed scale, presented at the Wadden Sea Drone Workshop in Groningen (Laura Govers, pers. comm.):

0) No reaction
1) Looks at the drone and/or turns away from the drone.
2) Slow movement (walking, swimming) away from the drone.
3) Takes flight but resumes original activity within 1-2 minutes.
3a) Takes flight and lands within 200 metres of the original location.
4) Takes flight and stays airborne while the drone is flying.
4a) Takes flight and lands more than 200 metres from the original location.
4b) Takes flight and lands more than 500 metres from the original location.
5a) Aggressive behaviour towards the drone.
5b) Takes flight and cannot be tracked by the observer.

The vast majority of the bird species studied did not react, corresponding to a score of 0 on the disturbance scale (Figure 5.1.2). Only in a colony of Black Guillemots did the birds react to the drone and they took short flights, corresponding to a score of 3-3a. No disturbances from the drone in the range of 4 – 5b were recorded in the experiment, regardless of how close the multirotor drone came to the colonies (Holm *et al*. 2018).

**Figure 5.1.2.** One of the species that does not react to a multi-rotor drone flying close is the spoon stork. Note that it is possible to record breeding success without the birds leaving the nest. Photo taken from a DJI Phantom 4. Credit: Thomas Eske Holm.

As the experiment showed, most nesting birds do not noticeably react to overhead drones, a finding that has since been documented in many other studies. Leija *et al.* (2023) reviewed 17 studies of disturbance by drones and concluded that ground colonial nesters showed no strong evidence of disturbance effect. In contrast, solitary breeders nesting off the ground, like birds of prey, showed strong evidence of a disturbance effect. Overall, they concluded, that the use of multi-rotor drones has relatively little disturbance effect on nesting birds. Fixed-wing drones can resemble predators to some bird species, such as the Eurasian oystercatcher, prompting a reaction (Holm & Bregnballe 2019).

To minimize disturbance when monitoring birds of prey nests, a Danish study demonstrates that these can be observed undisturbed with a multirotor drone from several hundred metres away using an attached zoom camera (Holm *et al*. 2022a, Holm *et al.* 2023).

Use of drones as a supplement or as an alternative to traditional monitoring can, in many cases, minimize disturbance to birds. Traditional counts from the ground may, in some instances, require moving directly into the colony, unintentionally or intentionally causing birds to take flight (Figure 5.1.3).

**Figure 5.1.3**. An employee from Aarhus University entering a colony of Sandwich Terns. Traditional counts from the ground may require moving directly into the colony, causing birds to take flight. Credit: Thomas Eske Holm.

Although such disturbance is usually relatively short-lived and may only correspond to a passing predator, it can lead to predation of eggs and chicks while parent birds are away from the nest (Carney & Sydeman, 1999). This applies to both the species being monitored and other species nesting in or in the immediate vicinity of the colony. Large gulls such as Lesser Black-backed Gull *Larus fuscus*, Great Black-backed Gull *Larus marinus* and Herring Gull are opportunistic in their foraging and readily prey on nests of, for example, cormorants, waterfowl, or other gulls, when the opportunity arises. Therefore, particular caution is required if nests in a colony are to be counted by walking through it, especially if large gulls are breeding in the immediate vicinity of the colony.

Holm *et al*. (2018) described an example where a Common Eider nest was visited by herring gulls and black-backed gulls after the female was scared from the nest by a counter, a scenario also described by Stien & Ims (2016). Gulls can also prey on each other's nests. There is also a risk that the counter may step on nests concealed in the vegetation. In most cases, it is possible to entirely avoid disturbing breeding birds when using a drone for counting. The disturbance effects and potential consequences that may arise from a traditional count can thus often be reduced or indeed eliminated by using drones in the monitoring of species suitable for this method.

## 5.2 Target species

Breeding bird monitoring using drone transect flights to simultaneously count numbers of birds/nests present is particularly well-suited for colony breeders, as their breeding areas can be easily defined. In the Wadden Sea and along the East Atlantic Flyway, several species have been successfully monitored in this way. Here, we will provide some examples of breeding bird species in the Wadden Sea that are most suitable for monitoring and counting using drones. Furthermore, we will provide examples of methods to monitor more challenging species that breed as dispersed nesters.

The two Wadden Sea workshops on use of drones to monitor waterbirds (see above and Appendix I) included presentations on experiences from using drones to count the following species on their breeding sites: Eurasian Spoonbill *Platalea leucorodia*, Great Cormorant *Phalacrocorax carbo*, Common Eider, Herring Gull, Lesser Black-backed gull, Black-headed Gull and Sandwich Tern *Thalasseus sandvicensis*, each of which we explore in more detail below.

### 5.2.1 Spoonbills

Eurasian Spoonbills are large white birds that are distinguishable from herring gulls that also breed on coastal meadows and in reedbeds. Their nests, often large and tall, are easily identifiable and locatable in drone images. Utilizing drone photos allows for not only counting the number of adult birds but also tallying the number of nests and determining if there are chicks inside or outside the nests, providing insight into the colony's phenology and productivity (Holm & Bregnballe, 2019). However, to know more precisely when the eggs have hatched or when the chicks will leave the nest, it often requires multiple flights.

It is not possible with a drone to achieve as precise a registration of nest content as by visiting the colony on foot, because spoonbills do not react to the drone, and many birds will remain on the nests, making it impossible to determine the nest content from photos. Monitoring colonies on coastal islands by deploying a drone from the mainland can be advantageous, avoiding the need to wade or sail to the island. The use of a drone is also suitable in locations where, for example, dense vegetation makes it challenging to locate nests from the ground. Some colonies are exclusively monitored using drone images to avoid disturbance and predation (Skriver, 2022).

### 5.2.2 Cormorants

Cormorants generally do not react to the presence of drones in breeding colonies (Rasmussen 2016, Bregnballe & Nitschke 2016, Holm & Bregnballe 2019). Cormorants are large birds that are easily identifiable, and their nests are usually easy to spot in drone images (Figure 5.2.2.1). Ground-nesting colonies are often divided into well-defined sub-colonies, which are easily visible from the air. Therefore, it is typically sufficient to locate and photograph individual sub-colonies with the drone, and there is rarely a need to conduct transect flights over larger areas.

As long as the ground-nesting cormorants have eggs in their nests and the birds remain on the nests during drone photography, counting occupied nests in drone images is usually straightforward. However, newly built or incomplete nests (where incubation has not yet begun) can be challenging to identify with certainty. Nests where incubation has been ongoing for some time, resulting in whitewashed surroundings and a brooding bird in the nest, are easily recognizable. If photography occurs later in the season (e.g., during June), there is an increased risk that counts from drone images will underestimate the actual numbers.

**Figure 5.2.2.1**. Ground-nesting colonies of cormorants are easy to monitor and count. Credit: Thomas Eske Holm.

Cormorants often steal nesting material from other nests when the opportunity arises. Therefore, nests where the breeding attempt is abandoned may quickly disappear. In colonies where cormorants breed on the ground, some nests may also be deserted by the cormorant chicks when they reach an age of approximately 20-25 days, after which the nests can disappear. These conditions are applicable during a direct on-foot count in the colony as well, emphasizing the importance of timing the count optimally in relation to the colony's phenology.

### 5.2.3 Gulls

Species such as the Herring Gull, Great Black-backed Gull, Lesser Black-backed Gull, Common Gull, and Black-headed Gull, often breed in larger, dense colonies that are highly suitable for monitoring through drone transect flights (Figure 5.2.3.1). Experiences, as demonstrated by Holm & Bregnballe (2019), show that drones can accurately assess the total number of individuals of each gull species in colonies with a relatively high or even very high degree of precision. Drones have proven to provide much more accurate figures than traditional monitoring methods involving binoculars or telescopes, where counting is done from more or less elevated observation points or by walking transect through colonies (with associated disturbance).

The number of breeding pairs is often estimated by multiplying the number of birds present in the colony area by a factor of 0.7, assuming that some of the partners to incubating individuals are away on foraging trips (see Hälterlein *et al*. 1995). This conversion has inherent uncertainties, partly because the number of birds within the colony area will vary from species to species, from colony to colony, depending on the time of day, and for colonies in the Wadden Sea, also depending on whether it is high tide or low tide. If drone images are of sufficient quality, it is often possible to estimate the colony size by only counting the birds on nests. There is a reasonably consistent correlation between the estimated number of breeding pairs by multiplying the total number of individuals by 0.7 and the figures obtained by assuming that all birds sitting down were on a nest (Holm & Bregnballe 2019). Corregidor-Castro *et al*. (2022) showed that for Herring Gulls and Lesser Black-backed Gulls the number of occupied nests/breeding pairs could be estimated accurately by multiplying the number of counted individuals with a 0.7 conversion factor.

**Figure 5.2.3.1**. One of 900 photos of a herring gull colony taken during a transect flight of Venø, Denmark in 2021. Credit: Thomas Eske Holm.

During the Wadden Sea Workshop in Hamburg in February 2023, Martin Schulze Dieckhoff suggested to carry out two flights on the same day and only take birds on exactly the same position as breeders, excluding non-breeding birds. Flying should preferably be done at low tide, where most non-breeders are outside the colony.

In general, it is recommended to fly drones at low altitudes, preferably in the range of 25-40 metres, during gull monitoring. Flying at low altitudes over larger islands will naturally result in the photography process extending over a longer period (requiring more battery life), and a substantial number of photos will subsequently need to be stitched together. Additionally, it is advised to fly in sunshine and preferably in the morning or alternatively late in the afternoon/early evening. This increases the chance of birds casting easily visible shadows. Finally, monitoring should take place at a point in the breeding season when the eggs have not yet begun to hatch, which is also a general recommendation for bird counts in general. Moreover, it is advantageous for image analysis that photography is conducted before vegetation has grown to a height that significantly reduces the visibility of incubating birds. The probability of correctly distinguishing individuals on nests from individuals that are not on nests can be improved markedly by photographing the colony two or three times with an interval of at least five hours or on subsequent days (e.g. Sardà-Palomera 2017 and presentations by V. Hennig and M.S. Dieckhoff at the drone workshop in Hamburg 2023). It is here assumed that having a bird on exactly the same spot-on subsequent photos can be taken as evidence of having a nest present. Sardà-Palomera (2017) has demonstrated how multiple flights allow for a continuous collection of spatial and temporal data from colonies.

### 5.2.4 Sandwich Terns

Sandwich Terns breed in particularly dense colonies, often in tight enclaves within larger Black-headed Gull colonies. Due to their concentrated nature, it is easy to count the total number of adult birds in the colony area from just a few drone images (Figure 5.2.4.1). In this case, one can count all adult birds and multiply by a conversion factor, as described in Hälterlein *et al*. (1995). This method can be employed when it is challenging to estimate the number of standing and nesting Sandwich Terns in images taken directly from above.

**Figure 5.2.4.1**. Part of a colony of Sandwich Terns taken during a manual flight. Credit: Thomas Eske Holm.

When monitoring with a drone, another method presented at the Wadden Sea Workshop in Groningen in 2018 can also be used (Spaans *et al.* 2018). In this approach, one begins by counting the number of standing and nesting birds in a representative section of the colony. This is done from a distance using a telescope (but can probably also be done with an oblique photo from a drone). The count should take place early in the morning when the terns, having flown on their first foraging trip after the night, result in the minimum number of standing birds in the colony. Afterward, the percentage of standing birds in the surveyed section is calculated as a proportion of the total number of birds. In the Dutch study, the proportion of standing birds ranged between 3.2% and 7.8% (Spaans *et al.* 2018). The colony is then photographed immediately afterward, and all Sandwich Terns are counted in the images. By subtracting the percentage represented by standing birds, the number of nests is calculated. For example, if there are 5% standing birds and 200 birds are counted in drone photos, the estimated number of nests or breeding pairs would be 190.

### 5.2.5 Black Tern

Black Terns *Chlidonias niger* inhabit freshwater environments with excellent water quality, a rich food supply, and suitable nesting opportunities. They are typically found in shallow lakes, marshes, and ponds, preferably with associated gull colonies. These colonies are relatively dense, making them well-suited for monitoring using drones. Often, the colonies are concealed by reed beds or similar vegetation, and a drone provides a comprehensive overview of the area where Black Terns breed. Depending on the size and location of the colony in the wetland, either transect flights or manual flights can be employed for monitoring.

## 5.3 Dispersed and cryptic species

Some bird groups fall outside regular monitoring programmes due to their cryptic nature, unique life histories, and/or habitats that are difficult to access. Different approaches are employed and spearheaded for monitoring these species using drones.

In recent years several studies have used drones equipped with thermal cameras to monitor dispersed and concealed-breeding species. Valle & Scarton (2019) demonstrated that monitoring of the cryptic Redshank *Tringa totanus* species breeding in saltmarsh with a drone proved significantly more efficient compared to ground counts conducted by individuals. However, with the method used, the birds were flushed from the nest, with the drone flying at a height of 10 metres and a speed of 15 m/sec. Likewise, Bushaw *et al.* (2021) found that drone-based thermal imaging effectively doubled the detection of duck broods in wetlands compared to traditional methods, completing surveys three times faster. In Germany, Israel and Reinhard (2017) detected nests of Northern Lapwing *Vanellus vanellus* using drones equipped with thermal cameras. Additionally, McKellar *et al*. (2020) successfully detected various waterbirds using a dual visible-thermal camera approach, enabling bird identification with the help of thermal images with no observable disturbance of the breeding birds. Recently, considerable benefits have been shown for using thermal imaging for detecting dispersed and irregularly grouped cliff nesting seabirds (Castenschiold & Hammer 2021). Here the detection rate of especially chicks, which often blend in well with the surroundings, steeply increased. Lastly, certain dispersed species, such as birds of prey, are highly sensitive to drones. However, they can be monitored without disturbance from a distance of several hundred metres using a drone equipped with a zoom camera (Holm *et al.* 2022a, Holm *et al.* 2023).

### 5.3.1 Surveying in the dark

Drones equipped with thermal cameras present promising new aspects for monitoring as it enables surveying in the dark at night. Nighttime surveys have the potential to mitigate traditional challenges, such as disturbance in the area. This can be due to less vigilance of the birds caused by the lack of natural threats from above at night, such as birds of prey, which makes the birds less prone to react to potential aerial threats. Furthermore, a lowered and more stable ambient temperature during the night helps to capture more uniform thermal imagery with an often significantly higher contrast between the bird’s heat signature and the surrounding area. However, the lack of light means complete reliability on thermal detection and differentiation according to the specific heat signature of the target birds and species. Using a drone with thermal sensor J.F. Castenschiold (unpublished data) successfully located and quantified breeding Common Snipe in grass fields on small islands in the Faroe Islands (Figure 5.3.1.1). By using infrared drone imagery active nest sites could be reliably pinpointed according to their unique heat signatures and further differentiated from occurrences of resting or feeding individuals, by conducting repetitive surveys on separate nights.

**Figure 5.3.1.1.** Photo of two Common Snipe taken with a normal camera (left) and thermal camera  (right). The comparison is used for confirmation and verification of species and the corresponding heat signature. Credit: Johan H. Funder Castenschiold

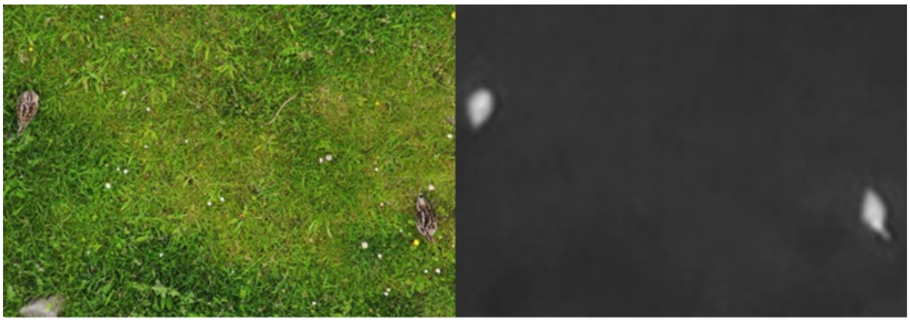
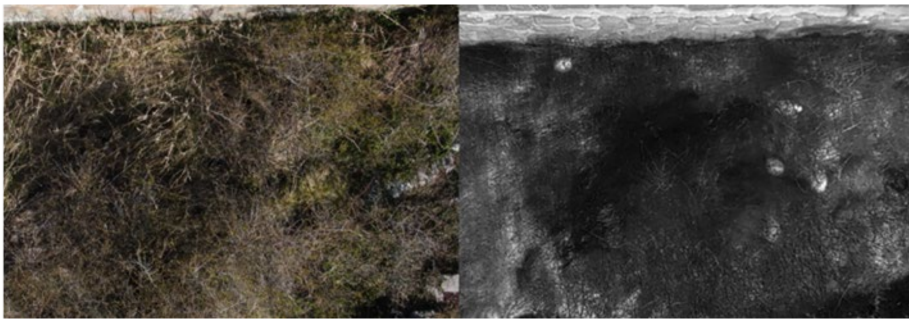


**Figure 5.3.1.2**. Photos of a breeding area for Common Eiders taken with a normal camera (left) and thermal camera (right). The thermal camera clearly shows where the breeding eiders are located beneath the otherwise nearly impregnable and densely covered canopy of scrub and foliage. Credit: Johan H. Funder Castenschiold.



Brooding Common Eiders abundance have also been monitored using thermal imagery to great success. Here a thermal camera showed the ability to detect and quantify individuals nesting under scrub and in difficult accessible island areas on Ertholmene in Denmark, the Faroe Islands (Figure 5.3.1.2). and on the Dutch Wadden Sea islands (J. Heusinkveld & K. Oosterbeek in litt.).

When performing surveys at night, it is important to consider the need to rely on uniquely definable heat signatures to differentiate between different species sizes. Here precise flight altitudes during the survey (below ~ 30 m) are essential to obtain heat signatures with a stable number of pixels, which can be transformed to estimate actual bird body size. This can be obtained by utilising a Digital Elevation Model DEM that in turn, for many newer drone models, enable an automated following of terrain by the drone. By maintaining even flight altitude, the ground resolution is stable and different bird body sizes should be detected and accurately differentiated to putative species, based on the appearance of their unique heat signatures.

# 6 Monitoring of roosting birds

Counting migratory birds present distinctly different challenges compared to counting breeding birds. Breeding birds tend to remain at or near their nests, whereas many migratory birds are only temporarily stationary at stopover sites. Additionally, migratory birds are often far more sensitive to drones, and the monitoring methods used for breeding birds may not be suitable for monitoring roosting birds in many cases (Holm *et al*. 2018).

## 6.1 Disturbance

Studies have demonstrated that many roosting waterfowl can be observed with drones without causing disturbance. This is particularly evident for species like ducks, geese, and swans, which commonly roost on lakes or other bodies of water and may not react to the presence of a drone when they are on the water (Holm *et al*. 2022a). This includes species such as Tufted Duck *Aythya fuligula*, Greylag Goose *Anser anser*, Barnacle Goose *Branta leucopsis*, Mallard *Anas platyrhynchos*, Common Pochard *Aythya ferina*, Gadwall *Mareca strepera*, as well as moulting Red-breasted Merganser *Mergus serrator* and moulting Mute Swan *Cygnus olor*. It seems that many species are unaffected by drone monitoring over water. However, if birds are on land, like a lakeshore, field, sandbank, or beach, they often respond to a drone by taking flight or entering the water if they are close to a lake or the sea.

Waders on land typically react readily and often from a considerable distance to a drone. This encompasses species such as Dunlin *Calidris alpina*, Northern Lapwing, and Eurasian Oystercatcher *Haematopus ostralegus*. However, if waders are standing in shallow water, their reaction is less pronounced or may not occur at all. For instance, high tide roosting Pied Avocets *Recurvirostra avosetta* standing in shallow water often do not react to a drone and can be flown over without causing them to take flight. Nonetheless, it's generally advisable to exercise caution when flying in areas with many species of waders, as experience indicates that a drone can easily flush thousands of birds (Holm *et al*. 2022a, Wilson *et al*. 2023). In Australia, Wilson *et al*. (2023) found that for all species of waders, there was less than a 20% probability that they would take flight when approached by a drone at vertical distances above 60 metres. Only the Eastern Curlew *Numenius madagascariensis* could not be approached at any vertical distance below the recreational drone limit of 120 metres without inducing flight. In many cases, 60 metres or more can be too high an altitude to recognize bird species in drone pictures. Operators should be alert to the fact that most waders will react to drones at the escape distance of the species showing the lowest tolerance, so mixed flocks will cause particular challenges in this respect.

## 6.2 Target species

In the Wadden Sea and along the East Atlantic Flyway, numerous waders, ducks and geese are routinely monitored in the traditionally way, using ground count observers. However, many of these species pose challenges for drone-based surveys as they are easily disturbed by the presence of drones and quickly take flight. In this context, we will in the next sections offer examples of bird species roosting and foraging in the Wadden Sea that are conducive to monitoring and counting using drones, as well as species that present difficulties in monitoring.

## 6.3 High tide counts

Monitoring migrating birds typically involves counting at specific sites where the birds are most aggregated at roosting sites. To track changes in abundance over time, coordinated counts covering large areas are employed to prevent double counting the same birds in different locations. In areas affected by tidal influence, these counts are often conducted during high tide when the birds are more concentrated, less mobile, and closer to vantage points on land, facilitating observations.

### 6.3.1 Traditional ground counts

Traditional ground counts are currently the most widely used method for monitoring migratory birds along the East Atlantic Flyway, particularly where they gather in larger concentrations. This monitoring effort involves approximately 12,000 observers across 36 countries (van Roomen *et al.* 2022). The midwinter count is a strategy used to assess the size of many populations along the East Atlantic flyway during a period when they are concentrated in wintering areas. Population size and trends can be evaluated during the non-breeding season, when species like the European Golden Plover *Pluvialis apricaria* and Dunlin are more concentrated during migration periods (Gillings *et al*. 2012).

Ground counts typically rely on a local network of observers who possess intimate knowledge of the counting sites. They are less susceptible to weather disruptions compared to aerial counts and often yield results quickly. However, ground counts depend on the experience of individual observers, and the counts cannot be easily verified afterward. Additionally, when counting dense flocks on high tide roosts, a significant portion of the birds may be obscured by others, making some individuals undetectable (Castenschiold *et al.* 2023). Accessing certain counting sites can be time-consuming and come with logistical problems (e.g. remote islands or sand bars), and ground counts may require more observers to cover the same areas as manned aerial survey flights.

Ground counts are likely to remain the primary monitoring method for the foreseeable future. The question arises as to when and how drones can complement or replace ground counts, as well as aerial counts conducted from aircraft, and to what extent drone-based counts can be applied to study distribution at low tide.

### 6.3.2 Aerial surveys using airplanes

Aerial surveys from manned aircraft are utilized for surveying migratory birds offshore and on high tide roosts in the Wadden Sea. In the Danish Wadden Sea, aerial surveys have been a standardized component of avian monitoring for decades (Laursen & Frikke, 2013). Airplanes can cover large areas relatively quickly and reach inaccessible areas for ground counts or drone surveys. Offshore surveys typically involve transect flights, while coastal surveys follow designated routes covering the coastline, islands, and high sands. The standard altitude for these surveys is 75 metres (250 feet) and a speed of 185 km/h (100 knots).

The Danish aerial counts method involves manual counting by observers positioned on both the right and left sides of the plane, using dictaphones (Figure 6.3.2.1). Geographical reference is ensured by combining observation times with GPS tracks or assigning recordings to defined counting sites. After the survey, the recordings are transcribed into databases, which is a relatively quick process. These aerial counts do not entail identification or estimation using photos. Laursen *et al*. (2008) found that counts in the Danish Wadden Sea from airplanes had a detection rate ranging from 65% to 90% compared to ground counts, depending on species, density, and flock size. The best results were achieved with larger flocks and more visible species. Aircraft are often used in combination with ground counts to count birds in large areas encompassing various bird species.

**Figure. 6.3.2.1**. A view from inside a Partenavia P.68 Observer during an aerial survey. Credit: Thomas Eske Holm.

Kempf *et al*. (2015) conducted a survey in 2012 of the uninhabited barrier islands in Schleswig-Holstein in the German Wadden Sea. These islands had never been surveyed before because they were inaccessible to ground counts or ship surveys. SLR cameras with 12 MP and 16 MP and zoom lenses of 80-300 mm were used in this survey. Panorama photos were initially taken from a height of 610 metres, followed by oblique photos to avoid disturbing the birds. The survey found that more than 50% of all waders in the Schleswig-Holstein Wadden Sea could be counted on the barrier islands.

The development of technology led to the use of HiDef videos in offshore transect flights. The HiDef system, in use since 2009, consists of four high-resolution video cameras recording the sea surface at a resolution of 2 cm/pixel across a transect width of 544 metres from an altitude of over 540 metres. The cameras are slightly tilted to avoid reflections and data loss due to the sun, and the flight altitude prevents disturbance of resting birds, making surveys over wind farms possible (Weiss *et al.* 2016). The HiDef system was employed in 2015 in a pilot study to map migratory birds on the same barrier islands in Schleswig-Holstein as in 2012. It was possible to cover the outer sands during a single high tide period and document the high number of birds of 57 species in areas that are often difficult or inaccessible for drone surveys.

Manned aircraft surveys also have disadvantages, including high costs and significant data handling requirements, typically requiring experts. Additional drawbacks include vulnerability to weather conditions (which in combination with short daylight in winter may lead to very asynchronous counts), inability to fly low and slow enough for accurate counts, and the risk of injury or loss of life to pilots and researchers. However, manned aircraft surveys are often the only viable method for counting large areas or sand banks far from the coast.

### 6.3.3 Drone surveys at high tide roosts

As previously mentioned, counting roosting birds is not as straightforward as counting breeding birds, as birds not invested in defending a nest site are much more prone to general disturbance, more often easily take flight and will forsake areas subject to disturbance to move elsewhere. In Australia, Wilson *et al*. (2023) found that the response of mixed-species flocks was largely dictated by the most sensitive species within the flock. This may imply that nearby species are using sensitive species as sentinels to provide information about predators.

For drone surveys this complicates the flight protocol and therefore careful planning should be included prior to any monitoring efforts. At high tide roosts the limited available space, however, means that large aggregations of birds are constricted to relatively small areas with often no obvious alternative sites. The birds are therefore often less likely to give up their space and use energy to seek out another roost site.

**Figure. 6.3.3.1.** Aerial view of a major roost site at Rømø barrage in the southern part of the Danish Wadden Sea. Credit: Thomas Eske Holm.

In the Danish Wadden Sea studies have been conducted at important and major roost sites (Castenschiold *et al.* 2022, 2023; Holm *et al.* 2022a). The experiences from these pilot studies showed that it is essential to observe strict survey protocols in order to minimize disturbance from the drone and avoid flushing of the birds. Key findings include that drones should take-off at distances of above 500 m from the roost site and allow for habituation of the birds prior to any mapping missions. This habituation can in most instances be obtained by initiating the first couple of transects beside the roost site to allow for the birds to habituate and settle down before flying directly above the site. Often this will occur within the first 5 min. after introducing the drone in the area.

During drone surveys two types of responses should be considered (Castenschiold *et al.* 2023). Firstly, introductory responses, when the drone is introduced to the survey area (pre survey), and secondly responses triggered during the actual survey mission (during survey). Importantly, considerable species-specific differences in disturbances were experienced, highlighting the fact that greater precautions must be applied for surveys of waders and geese than for ducks and gulls. Further significant influences of physical factors, such as tidal level and wind speed, were detected when observing disturbance behaviour.

**Figure. 6.3.3.2**. When surveying roost sites it is important to observe caution and follow specific approaches to allow for habituation and avoid flushing of the birds. Image from video. Credit: Johan H. Funder Castenschiold.

At high tide roost sites, the high variety of species in differing sizes and plumages necessitates image quality of increased resolution in order to enable differentiation down to species level. Special care should be taken in regard to species like smaller Calidris waders, such as dunlins, and middle-sized Charadriidae waders, such as European Golden Plover and Northern Lapwing. This limits the possible survey altitudes and a strict operational "green-zone" for flight altitudes should be considered in respect to both limitation of responses and optimization of image resolution. The specific green-zone may be influenced by both choice of drone model, the mounted camera equipment, and local legal regulations (Castenschiold *et al.* 2023).

As with manned aircrafts, a key advantage of drone surveys at sites with high concentrations of birds, such as high tide roosts, is the facilitation of an aerial perspective of the area. This greatly helps to circumvent the considerable risk of overlooked birds when counting high tide roost from a ground perspective, where large parts of the birds can be hidden behind each other (Laursen *et al.* 2008). Drone surveys uniquely enable the easy acquisition of fine-scale spatial information on individual occurrences and distributions of different species among the gathering of roosting birds (Castenschiold *et al.* 2022). Firstly, this novel spatial information can markedly increase the overall counting precision. Additionally, such knowledge can offer valuable insights into intra- and inter-species interactions in the highly dynamic environment of a high tide roost site. Such findings can pave the way for studies of how the size and location of the roost sites in a surveyed area might affect the possible composition and distribution of occupying birds, together with an assessment of the carrying capacity of the area (Fig. 6.3.3.3).

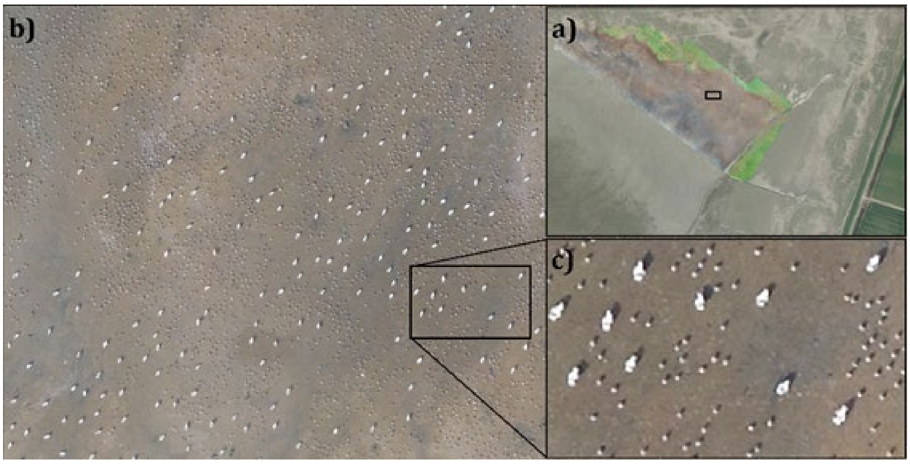



**Figure. 6.3.3.3.** Excerpt from generated orthomosaics of aerial surveys with a DJI Phantom 4 Pro at 75 m altitude. Upper right corner (a) shows the survey site in the study area and the georeferenced orthomosaic. b) Enlarged image depicts individual birds visible in the resulting imagery. c) Species present on the excerpt are Dunlin and Shelduck. The individual birds are clearly visible and identifiable. Furthermore, their fine-scale interactions and distribution can easily be assessed. Credit: Johan H. Funder Castenschiold.

In the German part of the Wadden Sea similar experiences have been reported from a study in 2023 (A. Kersten, BioConsult SH, personal communication). Here the key findings were that on smaller high tide roosts, where the birds are highly concentrated in limited areas, photographs of the birds could be taken obliquely from above but from a relatively long distance. Using a zoom camera the resolution made the images detailed enough so it was possible afterwards to count the birds. Depending on the quality of the photos, they could also determine the species of the birds; however, smaller birds like Dunlins and RedKnots *Calidris canutu* were difficult to differentiate from each other. Because the birds were distributed in a fairly narrow band along the coast, it was easier to ensure that the entire area was covered, and that all birds were captured in the photos.

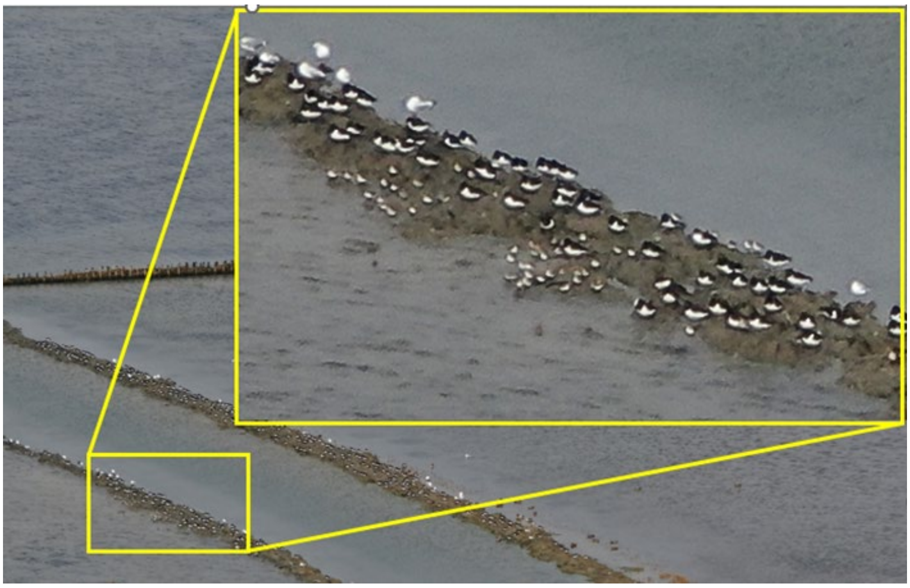


**Figure 6.3.3.4**. Picture of roosting Gulls, Oystercatchers, and Dunlins / Red Knots taken with a drone. By zooming in, the species can be counted and identified. Credit: BioConsult SH (bioconsult-sh.de).

In conclusion, drone surveys have great potential as a supplementary tool to traditional monitoring, both ground counts with telescopic optics and counts from manned aircraft. By providing precise information on numbers and distribution, implementation of drone censusing of high tide roosts will contribute to enhance assessments of trends of waterbird populations at both migratory and wintering hotspots.

### 6.3.4 Drone surveys of blind zones on intertidal flats

When counting waterbirds, the observer can be faced with the challenge of obstructed visibility stemming from non-visible stretches of intertidal flats, which can form behind uneven and elevated foreland or sandbanks. This is especially true when surveying with ground counts from vantage points on adjacent seawalls. Conditions like this are typical throughout much of the Wadden Sea where, at several places, a pronounced elevated foreland exists between the seawalls and the tidal flats, hiding potential feeding area of waterbirds from view. The extent to which such zones pose a problem in a given area and the effect of these to possibly obstruct the view of roosting or foraging birds remains relatively unknown.

The ability of drone surveys to detect and enable counts of birds in such otherwise unsurveyed areas and possibly mitigate the problem was investigated by Castenschiold *et al*. (2023), who studied the risk of overlooked birds while monitoring at several major roost sites in the Danish Wadden Sea. By firstly predicting the locations of the blind zones, drone surveys could successfully be deployed specifically to cover the identified blind zones and to quantify the number of birds, which were missed from the nearest vantage point (Fig. 6.3.4.1).

**Figure. 6.3.4.1**. Example of an elevated foreland with roosting waterbirds standing in near proximity to the edge and possibly hidden when observing from vantage points on the seawall in the Danish Wadden Sea. Credit: Johan H. Funder Castenschiold.

In the study, blind zones of ≤600 m were found to extend out on the intertidal flats along the investigated roost sites, where birds would normally be missed when observing from observers counting from the adjacent seawall. In these blind zones, a predicted 51–61% of the birds were not visible during a traditional ground survey. Moreover, the study predicted that different species were affected to a varying degree and that general habitat preferences together with the species' body height were important factors for the likelihood of a species to appear visible to observers while in the identified blind zones. Species of particular concern were small- and medium-sized waders, such as Dunlin, European Golden Plover, and Northern Lapwing together with Common Gull.

These findings suggest that there could be considerable and hitherto unforeseen risks of underestimation of waterbirds when performing ground-based counts, where coverage was considered unproblematic. Going forward, drone surveys could be well suited to cover these problematic blind zones and to detect otherwise undetected individuals. A compelling potential is thus shown for drones to complement waterbird censusing and help correct the estimates from traditional ground counts.

## 6.4 Low tide counts

The influence of the tide means that the feeding birds must remain continuously mobile, both within and between sites. Generally, counts have concentrated around high tide roosts, to gain the best impression of total numbers present at a site, at a time when birds are most densely concentrated and therefore least likely to be missed. Such information is vital for many purposes to do with flyway abundance, site importance and site management, but it is also important to know about how the same birds exploit the food resources of a site throughout the tidal cycle and their period of presence at a site.

Moreover, high tide counts may not always be feasible, dependent on site characteristics. In West Africa, mapping at low tide may be the only viable method for conducting surveys in areas where waders will roost during high tide in mangroves where they are functionally hidden and uncountable by regular means. However, there is a lack of knowledge and experience in monitoring birds at low tide.

Additionally, Clawley et al. (2022) looked at the use of drones to supplement data collection at low tide and found that the accuracy of counts may be compromised using current options of drone-based aerial surveys due to disturbance caused by the drone, as reported in published studies (Jarrett et al. 2020). They also concluded that further investigation is warranted.

## 6.5 Lakes and open water

In a study from Denmark, Holm *et al*. (2022a) conducted numerous experiments using drone surveillance of birds on lakes and open water. The conclusion was very clear: none of the birds of any of the species studied showed any noticeable reaction to drones.

One of the experiments was carried out at a lake where a large flock of Tufted Ducks was roosting. Initially, these ducks were manually counted through a telescope, totalling 1,900 individuals. In the experiment, a small Mavic 3 drone was flown up to a height of 120 metres and then over a large flock of Tufted Ducks roosting on a lake. Since none of the birds showed visible behavioural reactions, the altitude was gradually lowered to as low as 10 metres above the Tufted Ducks. Surprisingly, even at this height, there were no noticeable reactions from the Tufted Ducks (Figure 6.5.1).

**Figure 6.5.1**. Tufted Ducks captured from a DJI Mavic 3 drone at a distance of 10 metres. Credit: Claus Lunde Pedersen.

Subsequently, the larger DJI Matrice 210 was deployed and flown over the birds at a height of 50 metres. There were no noticeable reactions from the Tufted Ducks, which remained still on the water surface. Following this, a transect flight was conducted at a height of 50 metres, covering the part of the lake where the Tufted Ducks were roosting. The number of Tufted Ducks in the composite image was later estimated to be 2,249 individuals, which was 18% more than the 1,900 counted with the telescope. Thus, the traditional counting method, undertaken by an experienced observer, underestimated the number of Tufted Ducks present.

Large lakes, such as those extending to 100 hectares or more, can be time-consuming to monitor with transect flights, but this may be necessary if the birds are widely dispersed. The disadvantage is that a disturbance event (such as an eagle flushing the sitting birds) can quickly disperse the birds in mid-drone flight, causing the images to inaccurately reflect the correct number of birds present originally. However, birds on lakes are often concentrated in a smaller area, for instance to seek shelter from the wind. In such cases, a transect flight over part of the area may suffice, or a drone count can be combined with a traditional count by either 1) manually counting smaller flocks in the remaining parts of the lake, or 2) manually flying over the smaller flocks and taking pictures. It is important to keep track of which areas have been photographed and which ones are missing when flying manually.

Holm *et al*. (2022a) repeated the experiments in a fjord with moulting Mute Swans, moulting red-breasted mergansers, Eurasian Coots *Fulica atra*, and Greylag Geese, and these species could also be monitored on the water surface without showing any reactions to the presence of the drone. These experiments were repeated by flying drones over a lake with roosting Barnacle Geese. These geese also showed no detectable reactions to the drones and could be easily observed from the air. However, when flying drones near foraging Barnacle Geese on meadows and fields, Holm *et al*. (2022a) found that these geese reacted strongly to the drones and flew up from a distance of several hundred meters.

It therefore appears that roosting waterfowl on a water surface are not significantly affected by drones, unlike waterfowl roosting or foraging on land. The water surface seems to provide the birds with a sense of security, so they do not perceive the drone as a threat that needs to be responded to, although there may naturally be exceptions to this. However, these results are supported by the experiences from the Wadden Sea as described in Chapter 6.3.3.

**Figure 6.5.2**. Moulting Red-breasted Mergansers taken from a DJI Mavic 3 drone. Credit: Thomas Eske Holm.

# 7 Possibilities and problems now and in the future

Monitoring of breeding and migratory waterbirds along the East Atlantic Flyway has played a vital role in assessing the trends in abundance and distribution of long- and short-distance migratory waterbirds, their ecology and changing distributions for many years. However, there are several challenges relating to the disturbance caused by and the inaccuracies associated with the data generated by traditional monitoring methods. These factors have contributed to initiating and developing discussions examining the advantages of developing new methods for counting and mapping both breeding and resting birds, including the use of drones.

Monitoring of the numbers of breeding birds using transect drone flights has proven to be a reliable and precise method, particularly well-suited for colony breeders, as their breeding areas can often be easily defined and covered using such techniques. In the Wadden Sea and along the East Atlantic Flyway, several species such as spoonbills, gulls, cormorants, and terns have been successfully monitored. Areas for future consideration and investigation include optimising drone flights in relation to time of the day, time respective to the tide and determining what to count (nests/incubating birds versus individuals). Further species-specific investigation will generate advantages or disadvantages that need to be taken into consideration when establishing a census strategy. Moreover, the development and implementation of new methods must ensure backward compatibility with earlier counts undertaken by conventional methods. As we have shown, counts generated using drones often generate larger numbers compared to simultaneous tradition methods. It is also important that general increases in numbers of breeding birds, are recognised as being a function of the applications of new methods, not the result of any real increase in numbers.

Ongoing studies are exploring how to monitor dispersed and cryptic species on their breeding grounds with novel applications of innovation in drone technology. New methods, such as thermal and zoom cameras, are under development and will be increasingly available (including in multi-sensor platforms) soon. Until then, traditional monitoring may remain the best method in some cases.

Monitoring of roosting birds with drones is not as straightforward as counting breeding colonial birds, as roosting birds are much more dispersed and easily disturbed by drones. There is very little experience in monitoring birds at low tide, and there is a lack of studies and research into how this can be done to best effect. In terms of the current research agenda, there are several issues that need to be addressed when attempting to count waterbirds both on high tide roosts and for mapping birds throughout the tidal cycle on intertidal areas.

Firstly, some species of waders and terns are difficult to distinguish from each other on vertical photos taken from drones directly above the birds. Further development to resolve the challenges with so-called look-alike species could combine low altitude zoom photography with standard vertical imagery.

Secondly, remote high tide roosting areas can be very large, with aggregations of tens of thousands of waders. To monitor these areas with drones, Beyond Visual Line of Sight operations (BVLOS) can be required, as the pilot can only see the drone within 500 to 2000 metres away depending on weather and drone size. Beyond Visual Line of Sight operations (BVLOS) are only permitted in Europe if you meet the requirements from the authorities (See chapter 3.2.1). Given such permissions for such special operations are forthcoming, it is important that experiences are shared from such surveillance to ensure best practice to cover such important previously inaccessible aggregations of birds. As in the case of the previous category, it is important to maintain backwards compatibility in count time series to acknowledge the contribution of applying new methods to the apparent increase in total numbers of waterbirds present.

Thirdly, roosting and foraging birds are more restless than breeding birds and often move from place to place. Large areas must therefore be covered by drone flights as simultaneously as possibe before the birds have time to move, which can be challenging.

Finally, birds are easily flushed by unfamiliar flying objects such as drones, even at a long distance, and effective specialised monitoring methods therefore may still need to be developed. However, in smaller areas where the birds are concentrated, experiences have showed that pictures can be taken obliquely from above offering a way forward, but this approach may not be feasible everywhere.

In conclusion, for birds outside the breeding season, many areas cannot be monitored with drones alone because they are (i) too large, (ii) because birds move during drone monitoring flights or (iii) because bird are disturbed by the drone. However, drones can be very suitable as a supplement to traditional surveillance in these areas, especially in situations where the birds are difficult or impossible to count traditionally. Drones can be particularly useful in areas that are often skipped during normal censuses due to their inaccessibility but can be easily counted from the air with a drone. In general, drones should be viewed as a tool to complement ecological and environmental monitoring practices, rather than a replacement option (Baxter & Hamilton, 2018).

Manual evaluation of drone-acquired imagery remains the most common method of data analysis to convert images to numbers of birds present, but it can be highly resource demanding in terms of man-hours. In recent years, many projects have combined drones with automated or semi-automated detection of wildlife in imagery, which can be significantly faster compared to manual counting and bird identification and delivers more standardised (i.e. reproducible) results. We can expect more research into automatic species detection in the years to come, making future data analysis less time-consuming and more precise.

Any monitoring requires training in the methods used. Identification skills, tracking mixed flocks of thousands of birds moving on a mudflat, or counting a large group of breeding gulls through a telescope require expertise that requires training. Using a drone also requires training and licensing, even before the training starts. Intimate knowledge of drone equipment also requires frequent operation with any specific system.

We recommend arranging workshops for drone operators to encourage current and future drone operators in the development and evolution of best practice in avian drone monitoring techniques and to help refine the use of drones wherever relevant in the monitoring and research programmes related to breeding and migratory birds. Although there is an increasing body of literature supporting the effectiveness of UAVs as future monitoring tools in wildlife ecology, it is important to establish best-practice protocols for different types of tasks, especially in protected areas. Additionally, more studies are needed to improve data analysis and optimize the effort invested in monitoring.

# 8 References

Castenschiold, J.H.F. & Hammer, S. 2021. At finna fjaldar stovnar – sjófugla-eygleiðing við dronu. Frøði, 9–13.

Castenschiold, J.H.F., Bregnballe, T., Bruhn, D. & Pertoldi., C. 2022. Unmanned aircraft systems as a powerful tool to detect fine-scale spatial positioning and interactions between waterbirds at high-tide roosts. Animals, 12, 947.

EASA. 2024: https://www.easa.europa.eu/en/domains/civil-drones-rpas/-open-category-civil-drones

Islam, R., Stimpson, A. & Cummings, M. 2017. Small UAV Noise Analysis. Humans and Autonomy Laboratory, Duke University, Durham, NC, USA, 1–23.

Jarrett, D., Calladine, J., Cotton, A., Wilson, M.W. & Humphreys, E. 2020. Behavioural responses of non-breeding waterbirds to drone approach are associated with flock size and habitat. Bird Study, 67, 190–196.

Scobie, C.A. & Hugenholtz, C.H. 2016. Wildlife monitoring with unmanned aerial vehicles: Quantifying distance to auditory detection. Wildlife Society Bulletin, 40, 781–785.

ArcGIS Drone2Map. 2023: https://www.esri.com/en-us/arcgis/products/-arcgis-drone2map/overview

Baxter, P.W.J. & Hamilton, G. 2018. Learning to fly: integrating spatial ecology with unmanned aerial vehicle surveys. Ecosphere, 9(4).

BioConsult SH. 2023. First drone surveys for APIS project. https://www.bio-consult-sh.de/en/news/erste-drohnenfluege-im-projekt-apis

Bregnballe, T. & Nitschke, M. 2016. Danmarks ynglebestand af skarver i 2016. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 36 s. - Teknisk rapportno. 87. http://dce2.au.dk/pub/TR87.pdf

Bushaw, J.D., Terry, C.V., Ringelman, K.M., Johnson, M.K., Kemink, K.M. & Rohwer, F.C. 2021. Application of Unmanned Aerial Vehicles and Thermal Imaging Cameras to Conduct Duck Brood Surveys.Wildlife Society Bulletin, 45, 274-281.

Carney, K.M. & Sydeman, W.J. 1999. A review of human disturbance effects on nesting colonial waterbirds. Waterbirds, 22(1), 68-79.

Chen, A., Jacob, M., Shoshani, G., & Charter, M. 2023. Using computer vision, image analysis and UAVs for the automatic recognition and counting of common cranes (*Grus grus*). Journal of Environmental Management, 328.

Clewley, G.D., Calbrade, N.A., Austin, G.E., Frost, T.M. & Burton, N.H.K. 2022. A review of the BTO/RSPB/JNCC Wetland Bird Survey (WeBS) Low Tide Counts scheme with recommendations for its future operation. British Trust for Ornithology Pages, 52.

Corcoran, E., Winsen, M., Sudholz, A. & Hamilton, G. 2021. Automated detection of wildlife using drones. Synthesis, opportunities and constraints. Methods in Ecology and Evolution, 12, 1103–1114.

Corregidor-Castro, A., Holm, T.E. & Bregnballe, T. 2021. Counting breeding gulls with unmanned aerial vehicles: camera quality and flying height affects precision of a semi-automatic counting method. Ornis Fennica, 98, 33–45.

Corregidor-Castro, A., Riddervold, M., Holm, T.E. & Bregnballe, T. 2022. Monitoring Colonies of Large Gulls Using UAVs: From individuals to Breeding Pairs. Micromachines 2022, 13, 1844. https://doi.org/10.3390/mi13111844

Corregidor-Castro, A. & Valle, R.G. 2022. Semi-Automated Counts on Drone Imagery of Breeding Seabirds Using Free Accessible Software. Ardea, 110(1).

Castenschiold, J.H.F., Bruhn, D., Pertoldi, C. & T. Bregnballe, T. 2023. Monitoring roosting waterbirds: The use of drones to overcome the challenge of hidden individuals in blind zones on intertidal flats. Wader Study, 130(3), 239–253.

DJI Pilot. 2023. https://www.dji.com/dk/downloads/djiapp/dji-pilot

DroneDeploy. 2023. https://www.dronedeploy.com

Duffy, J.P., Cunliffe, A.M., DeBell, L., Sandbrook, C., Wich, S.A., Shutler, J.D., Myers-Smith, I.H., Varela, M.R. & Anderson, K. 2018. Location, location, location: considerations when using lightweight drones in challenging environments. Remote Sensing in Ecology and Conservation, 4(1), 7-19.

EASA 2023. https://www.easa.europa.eu/en/light/topics/drones

Gillings, S., Avontins, A., Crowe, O., Dalakchieva, S., Devos, K., Elts, J., Green, M., Gunnarsson, T.G., Kleefstra, R., Kubelka, V., Lehtiniemi, T., Meissner, W., Pakstyte, E., Rasmussen, L., Szimuly, G. & Wahl, J. 2012. Results of a coordinated count of Eurasian Golden Plovers Pluvialis apricaria in Europe during October 2008. Wader Study Group Bull, 119(2), 125–128.

Hayes, M.C., Gray, P.C., Harris, G., Sedgwick, W.C., Crawford, V.D., Chazal, N., Crofts, S. & Johnston D.W. 2021. Drones and deep learning produce accurate and efficient monitoring of large-scale seabird colonies, Ornithological Applications, 123(3).

Hellwig, U. 2009. Results of the quality assurance meeting in the framework of JMBB and TAMP on Neuwerk, 2009. Nationalparkverwaltung Niedersächsisches Wattenmeer: Institute for applied environmental biology and monitoring.

Holm, T.E., Kanstrup, N., Riddervold, M., Jensen, L.Ø. & Bregnballe, T. 2018. Brug af droner til overvågning af ynglende vandfugles reaktioner på menneskelig færdsel. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 32 s. - Teknisk rapport, no. 129. http://dce2.au.dk/pub/TR129.pdf

Holm, T.E. & Bregnballe, T. (red.) 2019. Overvågning af ynglefugle ved brug af droner. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 70 s. - Videnskabelig rapport, no. 311. http://dce2.au.dk/pub/SR311.pdf

Holm, T.E. & Bregnballe, T. 2020. Kortlægning af ynglefugle i Filsø, Birkesø og ved Gyldensteen Strand i 2020 ved brug af drone. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 25 s. – Fagligt notat, no. 2020-58

Holm, T.E., Pedersen, C.L., & Jørgensen, H. 2022a. Optælling af rastende vandfugle med droner. Metodeudvikling og undersøgelser af forstyrrelseseffekter. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 30 s. - Teknisk rapport, no. 251. http://dce2.au.dk/pub/TR251.pdf

Holm, T.E., Sørensen, K.T., Pedersen, C.L., Rasmussen, J.O., Rasmussen, S. & Langdal, J. 2022b. Visual Search. Et system til optælling af fugle og pattedyr på dronebilleder. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 44 s. - Teknisk rapport, no. 244.

Holm, T.E., Jørgensen, H. & Pedersen, C.L. 2023. Droner med zoomobjektiv giver helt nye muligheder i fugleovervågningen. Dansk Orinitologisk Forenings Tidsskrift. 117, 1-14.

Hälterlein, B., Fleet, D.M., Henneberg, H.R., Mennebäck, T., Rasmussen, L.M., Südbeck, P., Thorup, O. & Vogel, R. 1995. Vejledning i optælling af ynglefugle i Vadehavet. Translated by O. Thorup. – Wadden Sea Ecosystem No. 3, CWSS, TMAG, Joint Monitoring Group for Breeding Birds in the Wadden Sea, Wilhelmshaven.

Israel, M. & Reinhard, A. 2017. Detecting nests of lapwing birds with the aid of a small unmanned aerial vehicle with thermal camera. International Conference on Unmanned Aircraft Systems (ICUAS), Miami, FL, USA, 2017, 1199-1207.

Kellenberger, B., Veen, T., Folmer, E. & Tuia, D. 2021. 21000 birds in 4.5 h: efficient large-scale seabird detection with machine learning. Remote Sensing in Ecology and Conservation, 7, 445-460.

Kempf, N., Günther, K. & Fritz, V. 2015. Rastvögel auf Sandinseln im schleswig-holsteinischen Wattenmeer im Mai und September 2012. Vogelwelt, 135.

Kjølberg, K.E. 2016: Skræmte hjorte betyder droneforbud.Online artikel: https://www.dr.dk/nyheder/regionale/hovedstadsomraadet/skraemte-hjorte-betyder-droneforbud

Koffijberg, K. & Dijksen, L. 2007. Short report on Quality Assurance Meeting (QAM) on Texel in 2005. SOVON Vogelonderzoek Nederland.

Laursen, K., Blew, J., Bregnballe, T., Dalby, L. & Willemoes, M. 2008. Results of the quality assurance meeting in the framework of JMBB/TAMP on Mandø, 2008. Aarhus University, National Environmental Research Institute, Department of Wildlife Ecology and Biodiversity.

Laursen, K. & Frikke, J. 2013. Rastende vandfugle i Vadehavet 1980-2010. Dansk Ornitologisk Forenings Tidsskrift, 107(1).

Leija, C.D., Mirzadi, A.R.E., Randall, J.M., Portmann, M.D., Mueller, E.J. & Gawlik, D.E. 2023. A meta-analysis of disturbance caused by drones on nesting birds. Journal of Field Ornithology, 94(2), 3.

McKellar, A.E., Shephard, N.G. & Chabot, D. 2021, Dual visible-thermal camera approach facilitates drone surveys of colonial marshbirds. Remote Sensing in Ecology and Conservation, 7, 214-226.

Mpouziotas, D., Karvelis, P., Tsoulos, I. & Stylios, C. 2023. Automated wildlife bird detection from drone footage using computer vision techniques. Applied Sciences, 13(13), 7787.

National Drones. 2023. https://nationaldrones.com.au/

Naturstyrelsen. 2016. Droner må ikke forstyrre vandrefalke. Artikel online på https://netnatur.dk/droner-maa-ikke-forstyrre-vandrefalke/

Pix4D. 2023. https://www.pix4d.com/

Rasmussen, L.M. 2016. Rapport om optælling af Hættemåge vha. drone i Sneum Engsø 23. maj og 1. juni 2016. 2016. Tidal Consult.

Sardà-Palomera, F., Bota, G., Padilla, N., Brotons, L. & Sardà, F. 2017, Unmanned aircraft systems to unravel spatial and temporal factors affecting dynamics of colony formation and nesting success in birds. Journal of Avian Biology, 48, 1273-1280.

Skriver, J. 2022. Skestorke talt fra drone af frygt for sultne sølvmåger. BirdLife Denmark. https://www.dof.dk/om-dof/nyheder?nyhed_id=2095

Spaans, B., Leopold, M. & Plomp, M. 2018. Using a drone to determine the number of breeding pairs and breeding success of Sandwich Terns Sterna sandvicensis. Limosa, 91, 30-37.

Starnes, T. & Teuten, E. 2020. Drones for GIS – Best Practice. Royal Society for the Protection of Birds. Conservation Data Management Unit.

Stien, J. & Ims, R.A. (2016), Absence from the nest due to human disturbance induces higher nest predation risk than natural recesses in Common Eiders *Somateria mollissima*. Ibis, 158, 249-260.

UAV Coach. 2023a. Web site about EU drone regulations. https://uavcoach.com/drone-laws-in-the-european-union/

UAV Coach. 2023b. Flying a drone in Guinea Bissau. https://uavcoach.com/drone-laws-in-guinea-bissau/

Valle, R.G. 2021. Rapid drone semiautomated counts of wintering Greater Flamingos (*Phoenicopterus roseus*) as a tool for amateur researchers. Ibis, 164(1).

Valle, R.G. & Scarton, F. 2020. Drones Improve Effectiveness and Reduce Disturbance of Censusing Common Redshanks *Tringa totanus* Breeding on Salt Marshes," Ardea, 107(3), 275-282.

van Roomen, M., Citegetse, G., Crowe, O., Dodman, T., Hagemeijer, W., Meise, K. & Schekkerman, H. (eds) 2022. East Atlantic Flyway Assessment 2020.The status of coastal waterbird populations and their sites. Wadden Sea Flyway Initiative p/a CWSS, Wilhelmshaven, Germany, Wetlands

International, Wageningen, The Netherlands, BirdLife International, Cambridge, United Kingdom.

Weiß, F., Baer, J., Büttger, H. & Nehls, G. 2016. Digitale Videoerfassung der Außensände im Nationalpark Schleswig-Holsteinisches Wattenmeer Rastvögel, Seehunde und Kegelrobben; Flug am 15. Mai 2015. Im Auftrag von: Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein.

Wilson, J.P., Amano, T. & Fuller, R.A. 2023. Drone-induced flight initiation distances for shorebirds in mixed-species flocks. Journal of Applied Ecology, 60, 1816–1827.

Wirsing, A.J., Johnston, A.N. & Kiszka, J.J. 2022. Foreword to the special issue on 'the rapidly expanding role of drones as a tool for wildlife research'. Wildlife Research, 49, i–v.

# Appendix I

## Use of drones in bird monitoring in the Wadden Sea:

## Topics covered by the CWSS workshops in 2018 and 2023

### The workshops

The present report is largely based on the synthesis of results from two dedicated workshops, of which one was held in Groningen in March 2018, and the other held in Hamburg in February 2023. The workshops were organised by the Bird Expert Group and the Common Wadden Sea Secretariat (CWSS) under the umbrella of the Trilateral Monitoring and Assessment Program (TMAP). The workshops were part of the so-called Quality Assurance Meetings (QAM), which have had a long tradition in the trilateral breeding bird monitoring, to check and validate existing census methods. Both workshops focused on the use of drones in monitoring breeding bird abundance and distribution in the Wadden Sea and the second workshop included presentations on early experiences of using drones to monitor migratory birds at high tide roosts.

The first workshop was held at Groningen University in March 2018, attracting c.25 participants and included 7 presentations. The second workshop was held at the University of Hamburg in February 2023, which includedc 30 par-ticipants and included 15 presentations. The presentations were based on tests and studies conducted in the Netherlands, Germany and Denmark. Both workshops included follow-up discussions on various aspects related to the use of drones for bird monitoring work in the Wadden Sea.

### Topics covered by workshop presentations and discussions

The presentations illustrated the dynamic development of drones and their potential use in monitoring numbers of breeding pairs, breeding success and birds roosting at high tide. Most presentations reported the advantages of using drones that can achieve simultaneous high-quality counts of undisturbed breeding birds within a short timeframe. The first tests of using drones to count high tide roosting waterbirds suggest that applications of this technique will be far more challenging than one could hope for. The major challenges seem to be associated with the greater sensitivity of roosting birds to the sound made by the flying drone, although some species also apparently respond to the sight of the drone. There is, however, variation among species in their sensitivity to overflying drones when present at roosting sites.

The questions and topics covered by the presentations and in the following discussions included:

- What are the current limitations caused by *legislative issues*?
- What are the pros and cons of using different *types of drones*? (e.g. drone size, colour, type and noise in relation to the risks of causing undesired disturbance).
- What are the species-specific responses of birds to drones? Some species are evidently more sensitive than others, while some seem to habituate to overflying drones.

- What insight into possible *disturbance* do we get from the recent experimental studies? It was clear from several of the studies that use of drones as a supplement or as an alternative to traditional monitoring in many cases minimized the disturbance to birds.
- What are the recommendable *flight altitudes and safe operating distances* for photographing the different species to minimize disturbance?
- What *quality of photos* is required to ensure correct identification of the species on the photos taken from the drone?
- How do we provide *evidence for administrators and site-managers* that the use of drones can be implemented to improve survey efficiency whilst minimizing disturbance to birds?
- How can we *standardize the use of drones* in monitoring breeding birds in the Wadden Sea? For instance, with regard to timing in relation to breeding phenology, flying methods, analyses of photos, data handling and assessment. Monitoring guidelines for the usage of drones will help us in delivering consistent, comparable and harmonized information on the status of breeding birds in the Wadden Sea in the future.
- What research and development is required to *apply AI* to the processing of photos without risking too many mistakes in species identification and in correct counting?
- How do we *distinguish between standing and incubating birds* on photos taken directly from above? Experiences showed that much can be gained from choosing the right conditions (in terms of sunshine vs cloudy weather), the right time of the day (the angle of the sun and in relation to tide state).
- How do we *convert from the total number of individuals* present in the colony (in case we are unable to distinguish between standing and incubating birds) to numbers of breeding pairs/pairs with active nests?
- What have we learned about the *precision of results* from drone surveys compared to traditional counting methods? We require simultaneous counts by drones and traditional methods over a series of years so we can develop conversion factors that will help us ensuring comparability with counts conducted in earlier years.
- How can we use drones to *monitor breeding success* in colonies of waterbirds? Some presentation provided evidence of how to use of drones to provide reliable measures of breeding output in Sandwich Terns and Spoonbills.
- In what ways can photographing with *thermal cameras* help us in counting cryptic/elusive species and species that do not breed in colonies but breed dispersed in the landscape?
- Is it possible to get around some of the challenges associated with monitoring *roosting birds* by choosing certain types of drones and by flying the drones in particular ways?
- Can monitoring of *roosting birds* markedly improve the precision of high tide counts? (e.g. drones can overcome the challenge of hidden individuals in blind zones on intertidal flats).

The tests of pros and cons of using drones for monitoring breeding birds in the Wadden Sea have focused on several key breeding birds in the Wadden Sea including Eurasian Spoonbill, Great Cormorant, Common Eider, Herring Gull, Lesser Black-backed gull, Black-headed Gull, Sandwich Tern, Common Tern, and Pied Avocet.

Example of a drone photo of a group of nesting Spoonbills. The red circles denote active nests. The standing birds can be identified by their long shadow. Two incubating Lesser Black-backed Gulls are also visible on the photo. Credit: Martin Schulze Dieckhoff.

# USAGE OF DRONES IN ASSESSING BIRD NUMBERS ALONG THE EAST ATLANTIC FLYWAY

This report originates from a project entitled "Innovation for Migratory Bird Monitoring along the East Atlantic Flyway," funded by the European Commission's Structural Reform Support Programme. Traditional methods for monitoring breeding and staging waterbirds face challenges such as risk of disturbance and uncertainty about the precision of counts associated with the use of human observers, which has prompted the development of new drone-based remote methods for counting and mapping waterbirds. This report compiles experiences from attempts to monitor a range of waterbirds at different points in the annual cycle using drones. It is now evident that drones are very useful when monitoring species breeding in colonies, e.g. spoonbills, gulls and terns. Ongoing studies are still exploring the pros and cons of drone-based monitoring of cryptic species and non-colonial species of breeding waterbirds. Monitoring of waterbirds outside the breeding season with drones is often far more challenging due to their wider distribution in the landscape.  Some intertidal feeding species are also highly sensitive to approaching drones, especially when roosting at high tide. There is limited experience in monitoring birds foraging on sand- and mudflats at low tide. Further research is required to identify the precise circumstances under which drones are likely to greatly improve the quality of monitoring of waterbirds during and outside the breeding season.

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