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Short communication

Fine-scale bird monitoring from light unmanned aircraft systems

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Unmanned aircraft systems (UAS) are remote-controlled devices capable of collecting information from difficult-to-access places while minimizing disturbance. Although UAS are increasingly used in many research disciplines, their application to wildlife research remains to be explored in depth. Here, we report on the use of a small UAS to monitor temporal changes in breeding population size in a Black-headed Gull *Chroicocephalus ridibundus* colony. This method makes it possible to obtain georeferenced data on nest locations without causing colony disturbance, which would not otherwise be possible via direct ground observations.

Keywords: aerial survey, bird colony, investigator disturbance, remote sensing, waterbirds.

Monitoring is a central component of conservation that aims to gather data on species' status through time and space. However, monitoring can be expensive and difficult (Sutherland 2005). This difficulty is exacerbated in the case of cryptic species and species located in inaccessible places, as well as species that are easily disturbed by human presence, such as waterbird colonies (Rodway *et al.* 1996, Blackmer *et al.* 2004, Carey 2009). Thus, the development of new efficient methodologies for obtaining data on easily disturbed or difficult-to-access species is an important challenge. An attractive option for obtaining such data is to use remote-controlled aircraft systems.

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Aerial surveys using manned aircraft for wildlife research have been conducted for a broad variety of species (mammals, birds, etc.) and purposes (Sutherland 2005) but the method comes with problems and constraints (Watts *et al.* 2010), including high costs, local conditions at airports, difficulties with the geospatial accuracy of the acquired data and survey repeatability. Ecological studies undertaken at small spatial scales, on low budgets, in difficult-to-access areas or requiring repeated recording of data over short time periods are increasingly turning to unmanned aircraft systems (UAS) as an adequate and efficient alternative (Jones *et al.* 2006, Watts *et al.* 2008).

UAS with remote sensors are being successfully developed for agricultural monitoring (Berni *et al.* 2009, Gay *et al.* 2009), hydrological applications (Rathinam *et al.* 2007) and monitoring of forest fires (Casbeer *et al.* 2005). In all these cases, the authors aimed to develop a tool for obtaining information at a broad geographical scale. However, the use of UAS in wildlife and environmental monitoring is still in its infancy, emerging as a new and promising tool for remote monitoring (Watts *et al.* 2008, 2010).

Jones *et al.* (2006) pioneered the applicability of small UAS to wildlife monitoring and made several recommendations for using UAS in fine-scale studies. These guidelines suggested that the UAS should be based on an easy-to-use field tool, electrically powered, hand-launched, easy to transport and operable by only one or two people. The UAS should have a positioning system and any potential crash risk should be minimized.

There have since been few applied studies and field trials using UAS to survey wildlife. Koski *et al.* (2009) evaluated the efficiency of UAS for monitoring marine mammals and suggested that UAS surveys yield similar results to manned aerial surveys. These authors, however, conceded that the method needed improvements before becoming an efficient tool, as some species could not be detected. High-resolution images from UAS make it possible to identify some birds to species (Abd-Elrahman *et al.* 2005, Brush & Watts 2008), and even to count nests and eggs from the air (Sardà-Palomera *et al.* 2009). However, although studies have underlined the potential of UAS as a fieldwork tool for wildlife research, specific applications remain scarce, suggesting a need for further development and validation of new applications.

The aim of this study was to develop and test a light UAS as a tool to monitor the number of breeding pairs of Black-headed Gulls *Chroicocephalus ridibundus* in an easily disturbed and difficult-to-access colony. The Black-headed Gull is a common inland-breeding species in Europe that usually breeds in dense colonies of up to several 1000 pairs (Snow & Perrins 1998). Repeated nest visits to a colony can systematically flush all adult birds and disturb the breeding colony. Optimal timing of a number of colony visits is a crucial factor for estimating number of breeding pairs due to their spread of laying dates (Cramp 1983). Repeated colony visits are required for accurate colony size and nest distribution monitoring; however, such visits may not always be a viable option due to disturbance from human presence and its possible impacts, as also described for other gull species (Burger & Gochfeld 1983). Thus, using a UAS could make it possible to carry out continuous and detailed monitoring of a colony while minimizing disturbance.

We aimed to provide an example of UAS application as an effective field tool to monitor wild birds. To keep fieldwork effort to a minimum, results from two different aerial sampling approaches are presented and compared.

METHODS

Study species and site

The Black-headed Gull is a species included under Annex I as a 'sensitive species' (Regional laws Order 148/1992) in Catalonia, northeast Spain. In 2006, a new colony established in Estany d'Ivars i Vila-Sana (41.68°N, 0.94°E), a recently recovered 126-ha inland lagoon in Catalonia (Fig. S1). This colony is located on a central island, and the number of breeding pairs has so far been increasing. Since 2006, breeding population censuses had been carried out by two ground visits a year to count nests and ring fledglings, respectively.

The Black-headed Gull is a medium-sized bird (34–37 cm long with a wingspan of 100–110 cm) (Snow & Perrins 1998) that is easy to identify from the air because of its relatively large size, whitish body feathers and characteristic black head. The colony island is 180 m long and is situated 310 m from the nearest shore. The laying period of this colony spans from mid-May to early June depending on the year (J. Estrada, unpubl. data). Before the breeding period, 12 ground control points (GCPs) visible from the air were distributed across the island and were individually georeferenced using a GPS device.

Aircraft, camera and control systems

The UAS design was based on previously developed methodologies (Jones *et al.* 2006, Watts *et al.* 2010). However, due the specificity of our objective, the method was technologically simplified as much as possible. Our UAS was composed of a manually radio-controlled aerial platform, an image acquisition device and a positioning and navigation system. The total weight of the UAS was 2.0 kg, and the approximate cost of the model aircraft plus all extra components and camera was €1400.

We used an electrically powered commercial off-the-shelf radio-control model aircraft (Multiplex Twin Star II model, Hitec/Multiplex USA, Inc., Poway, CA, USA; wingspan 1420 mm) as an aerial platform. The aircraft was hand-launched for take-off, had no undercarriage, and only needed a few metres of flat area or soft vegetation for landing.

A Panasonic Lumix FT-1 (Osaka, Japan) digital photo camera with a 28–128 mm lens (F3.3–5.9) and 12.1 megapixel resolution was used to acquire images. The camera was located below the aircraft inside a specially designed expanded polystyrene box looking directly down and the trigger was activated mechanically by a servomotor. During flights, the camera was set in wide-angle lens position (28 mm), at highest resolution, with auto-focus prioritizing maximum shutter-speed and unlimited continuous shoot mode (1.8 frames/s).

To determine the precise position of the aircraft relative to the target we used GPS and a commercial first person view (FPV) flight system (FPV Systems) that was synchronized from a land station. The FPV system consists of a small video camera located in the 'cabin' of the aircraft and a GPS providing data on the geographical coordinates, altitude, speed and course of the UAS (Fig. S2). This information could be visualized on video in the video display FPV through an on-screen display system located in the aircraft. Video signals were then sent to a video display set on the ground, allowing the person controlling the UAS to pilot from the aircraft's perspective (Video S1).

The GPS signal was captured and received on the ground by a base station with a computer (laptop) connected to an independent receiver system. This shows and records the route of the UAS in the Google Earth (Google Inc., Mountain View, CA, USA) environment in real time, allowing UAS flight tracking. More detailed technical information about the design of the algorithms, devices and software system employed can be found in Gomàriz and Prat (2009) and Masmitja *et al.* (2010).

Image acquisition and analysis

Based on previous knowledge of breeding phenology, three flight days (17 May, 24 May and 1 June 2010) were set, with two daily flights over the colony. Daily flights were separated by at least 1 h to allow for detection of non-breeding birds that are likely to move their position. Movements of non-nesting Gulls are due to natural movements because of foraging trips or because they are scared and flushed by other animal (e.g. raptors). These movements can involve hundreds of Gulls at the same time and can occur frequently within 1 h, the interval between two flights. The UAS base station was established 470 m from the island on the lagoon shoreline. UAS speed over the island was 30–40 km/h, flying at 30–40 m above ground, and the camera trigger was activated in continuous mode during flyover. The in-flight altitude and camera focal length used allowed the whole colony to be framed in a single image (Fig. S3), and thus only one flight-line was needed in each flight.

Gulls were identified in each aerial image by their shape and colour. Subsequent data and image processing made it possible to identify and estimate the number of individuals and nesting pairs. With the aim of validating the estimations obtained from the UAS image procedure, the island was visited once (20 May) during the study period to monitor the total number of Gull nests with eggs or chicks. The GCPs made it possible indirectly to georeference the aerial images and confer spatial attributes to each image pixel. The best picture (focus and frame criteria) from each flight was selected (n = 6) and georeferenced using the GCPs to obtain a series of images from the Gull colony that could be perfectly superposed. From each selected image, a georeferenced point feature (hereafter 'gull point feature') was created over each Gull location using ARCGIS 9 (ESRI, Redlands, CA, USA). To evaluate colony disturbance due to UAS flyover, we calculated the percentage of Gulls flying in each image still. Two different methods were used to estimate colony size.

Sequential-image estimation method

The gull point features from the two images per observation day were used to identify and count the nests. A nest was considered active when gull point features had remained in exactly the same position between the two consecutive images. With this information, each nest location was digitalized to obtain a nest point feature covering nest distribution for every monitoring day. We also estimated the proportion of nests overlooked in each flight date (e.g. nesting birds flushed between flights or unattended nest). New nests appearing on a certain date and situated at the exact same position as a Gull in only one of the images from the previous flight date were considered overlooked nests from that previous date.

One-image estimation method

We explored this method with the aim to keep fieldwork effort to a minimum. Black-headed Gull nests are formed of shallow scrapes lined with pieces of vegetation and can vary greatly in size, from a simple scrape with little vegetation to larger structures (Snow & Perrins 1998). Consequently, some nests were easy to identify from the air but others were not. Furthermore, the UAS images made it possible to assess whether gulls were standing up or sitting down. We used the first image from the first sampling day to classify every gull point feature using the following criteria: definite nest (visible nest structure and bird sitting down), probable nest (bird sitting down but no visible nest structure) and no nest (bird standing up and no visible nest structure).

The accuracy of the one-image nest estimation method was compared with the sequential-image nest estimation method by calculating the percentage of false positives (gull point feature classified as a definite nest using the one-image method but not detected in the sequential-image method) and false negatives (gull point feature classified as no nest using the one-image method but detected as a nest in the sequential-image method) obtained.

RESULTS

Black-headed Gulls did not show any notable response to the presence of the UAS, and mainly remained static in the colony during flyovers. Only 1.25% (sd = ± 0.5%; n = 6) of the Black-headed Gulls were seen flying in the images from the UAS flights.

The sequential-image method yielded the number and a distribution map of all Gull nests for each sampling day (Figs 1 and 2). The maximum estimated number of nests was 244 on 17 May (Table 1). Although the total number of nests was lower on subsequent observation days, some new nests were recorded in the colony, mainly between the first and second flight day (Table 1). Six of the 22 new nests from the second date flight had a Gull in the same position in one image from the previous sampling day, suggesting nests possibly overlooked in the first flight.

Direct nest counts from the visit to the island on 20 May gave a total of 229 active nests. Comparing this result with the sequential-image estimation from 17 May, there was a difference of 15 nests (6.1%). With regard to 24 May, there was only a difference of two nests (0.8%) between UAS data and direct counting.

Using the one-image estimation method on the first image on 17 May, 227 gull point features were classified as definite nest and 54 as probable nest (Table 2). Comparing the two estimation methods (one-image vs. sequential-image), the proportion of false-positive and false-negative nests was 8 and 2%, respectively (Table 2). The one-image estimation method correctly classified 86% (n = 209) of definite nests and 54% (n = 29) of probable nests compared with the sequential-image method.

DISCUSSION

Fine-scale aerial images were successfully obtained from a UAS and used to estimate the number and distribution of nests on each sampling day in a colony of a disturbance-sensitive gregarious bird, the Black-headed Gull.

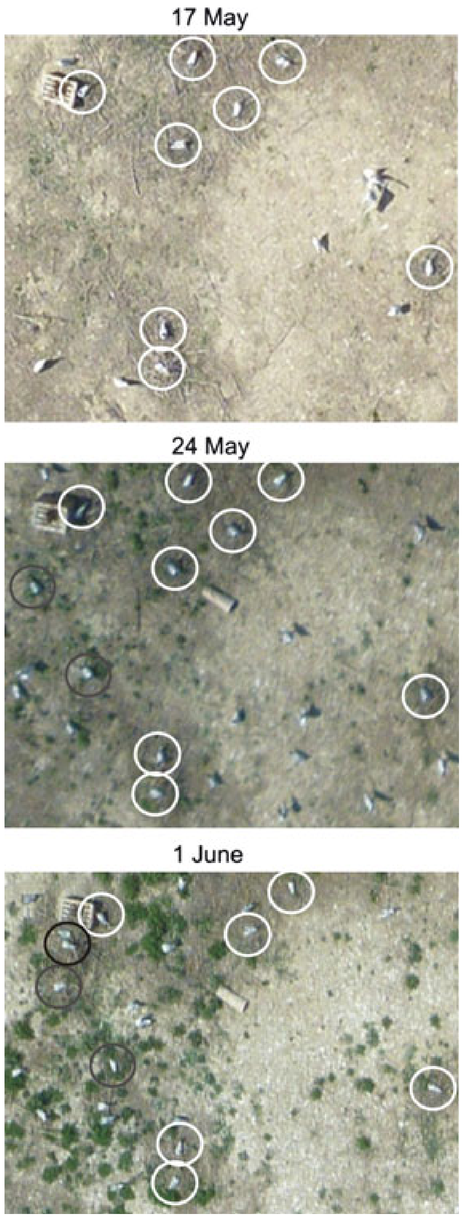

Figure 1. Enlarged image of the Black-headed Gull colony for each aerial sampling day. Nests detected on 17 May (white circles), nests detected on 24 May (grey circles) and nest detected on 1 June (black circle). The tile appearing on 24 May and 1 June is a rat trap placed during a site visit on 20 May.

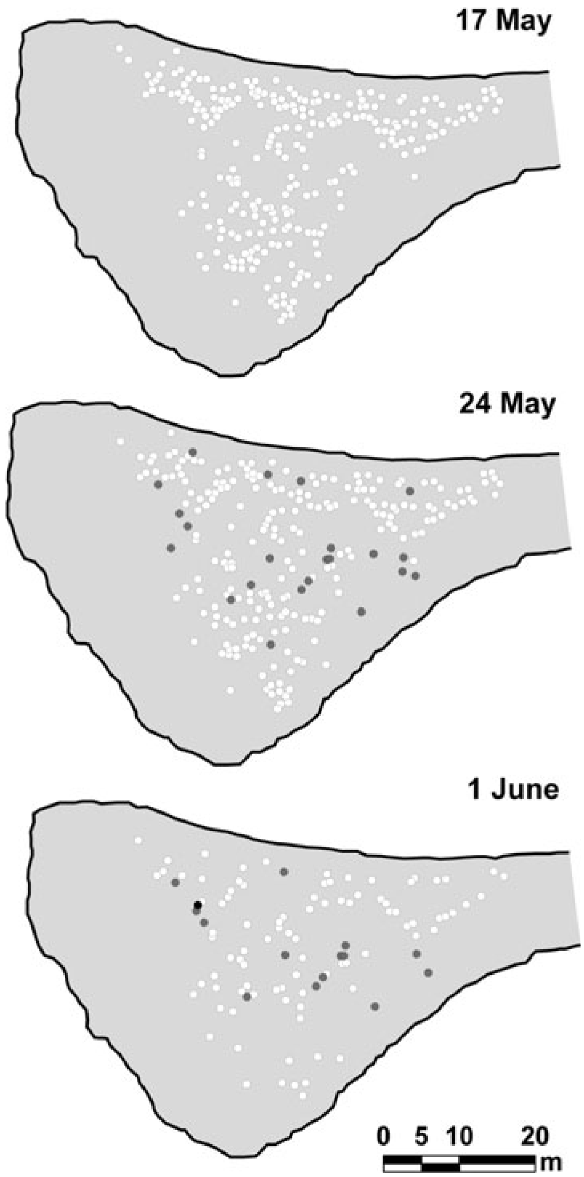

Figure 2. Map showing the distribution of Black-headed Gull nests in the colony for each aerial sampling day. Nests detected on 17 May (white dots), nests detected on 24 May (grey dots) and nest detected on 1 June (Black dot).

Therefore, this method makes it possible to obtain georeferenced data on nest locations without disturbing the colony, which would not otherwise be possible via direct ground observations. The small difference found in nest estimates between direct ground counts and sequential UAS images demonstrates that the method is highly accurate. However, even direct ground counts may not be 100% accurate due to human error. We added this information as a reference for comparison with the most common method when estimating colony-bird nest numbers. In contrast, with this UAS method several sequential aerial images can be obtained during the same sampling day, which allows information on potential census errors (Freckleton *et al.* 2006), such as standard errors and confidence intervals, to be obtained.

In the case of colonial breeding species with a spread of laying dates, continuous monitoring from UAS also

Table 1. Number of nests detected in each sampling day using the sequential-image estimation method and direct nest counts.

	Number of nests			
	17 May	20 May	24 May	1 June
UAS survey				
No. of nests already active at 17 May	244		209	92
No. of new nests between 17 May to 24 May			22	14
No. of new nests between 24 May to 1 June				1
Total	244		231	107
Direct nest counts		229		

Table 2. Comparison of the results obtained from observation of the first image on 17 May (one-image estimation method) with the results obtained using the sequential-image estimation method applied on the same day.

	Sequential-image estimation method		
	Nest	No nest	Total
One-image estimation method			
Definite nest	209	18	227
Probable nest	29	25	54
No nest	6	245	251
Total	244	288	

makes it possible to estimate temporal and spatial variation in number of breeding pairs. In this study, we detected changes in number of nests between sampling days. Those changes may be due to the hatching, the failure of already existing nests or the starting of new nests between two sampling dates. However, changes in nest numbers may also have been due to sampling errors. Underestimates as a result of Gulls not attending their nest and overestimates caused by loafing birds remaining in the same spot for more than 1 h may also be possible. Therefore, sampling accuracy could be increased with an increase in sampling effort by carrying out more flights during a sampling day.

The sequential-image estimation method can detect nesting birds without a visible nest structure from the air. In the case reported here, where nest structure size can vary significantly, sequential-imaging appeared to be the optimal method, as the one-image estimation method overlooked or wrongly assigned some nests. The accuracy of this one-image method relies on nest structure detection, making it dependent on image resolution and/or nest structure size. However, even if it is less accurate, the one-image method may be useful when working with more easily disturbed species or when time and budget limitations are a major consideration.

The application of UAS for wildlife monitoring may be affected by the limitations of range and flight duration or by factors affecting image resolution (see Jones *et al.* 2006 for details). The UAS designed in this study did not allow direct image referencing from airborne sensors, thus significantly reducing weight and cost. However, these more expensive and sophisticated technologies may not be so useful when the studies are done in a local area, and placing GCPs remains a viable option. On the other hand, up to now most aerial surveys of fauna have been commonly carried out from direct observations or aerial images from manned aircrafts (Wint 1998). However, manned aircraft have some restrictions: they need airfields or relatively big landing areas, limiting flight autonomy, and they are relatively expensive.

Aerial surveys from manned aircraft are often used when monitoring birds (Brush & Watts 2008) and bird colonies (Rodgers *et al.* 2005) over large geographical scales. However, there is ongoing discussion about the accuracy and variation in detection and identification (e.g. Rodgers *et al.* 2005, Conroy *et al.* 2008). In contrast, the UAS used in this study was designed as a fieldwork tool applicable to a small geographical scale, whereas other UAS can cover larger ranges (Jones *et al.* 2006, Watts *et al.* 2010). Thus, factors such as study scale, required accuracy and budget must be taken into account when choosing the optimal method for an aerial survey. In all aerial surveys, and often in terrestrial fieldwork, one of the main problems that can affect their application is adverse weather (wind and rain). In our example, the colony was located in a windy area; this affected to some extent the stability and speed of the aircraft and consequently the resolution of the images, which in some cases could have delivered better resolution under optimal conditions (see Sardà-Palomera *et al.* 2009).

This study showed that UAS can be used for accurate repeated censuses of a breeding colony at minimum cost with minimal colony disturbance. Recent developments in UAS, new online remote location devices and spatial data analysis tools may contribute to develop further applications of this method. The UAS method offers a tool with a great potential for field ornithologists, especially for obtaining information from difficult-to-access areas where human presence threatens to disturb the habitat or local fauna.

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The present study complies with the current Spanish legislation (*Ley* 21/2003, *Ley* 1/2011 and *Real Decreto* 1919/2009) governing aviation safety including radio-controlled aircraft. This legislation varies between countries. The radio frequency used for UAS radio control was 35 MHz. This is the frequency authorized for radio control in leisure applications in Europe under directive 1999/05/EC.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Figure S1. Aerial image of the Estany d'Ivars i Vila-sana. The location of the Black-headed Gull colony and the base station with the take-off and landing area are shown.

Figure S2. Photograph and detail of the UAS used in this study.

Figure S3. One of the image stills of the colony used to obtain the data, taken on the 17 May flight.

Video S1. Video obtained via the navigation system video camera from one of the flights carried out during colony monitoring. The video shows take-off and then flight over the lagoon and the island. The screen display gives UAS speed and battery charge on the left, location and distance from the base station at centre, and altitude in relation to the base station, horizon and time of flight on the right.

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