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Use of Drone Technology as a Tool for Behavioral Research: A Case Study of Crocodilian Nesting

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Abstract.—**Detecting cryptic behaviors without influencing the animal being observed is a challenging aspect of behavioral ecology. Such behaviors, often demonstrating habitat use, can play a crucial role in understanding wildlife monitoring and conservation. Crocodilian nesting is one such activity. Unmanned Aerial Vehicles (UAVs), or drones, are auto-piloted aircraft that can be used to map areas aerially using high resolution photography. Previously detectable through expensive helicopter surveys, this study sought to provide a new and less expensive method for the detection of estuarine crocodile nests in tropical forest ecosystems, as well as to propose additional applications of the technology based on field performance levels. The use of drones to detect crocodile nests is the first such application of the technology. We successfully identified two crocodile nests during the course of five flight hours (1550 ha; 15.5 km^2) of testing along the Kinabatangan River in Sabah, Malaysian Borneo, confirming the feasibility of the technology. We located these nests in close proximity to oil palm plantations, suggesting that low-level disturbance does not provide an obstacle to successful nesting. The potential to identify nests within unprotected forest could lead to additional protected areas being listed, and the effective management of crocodile nesting habitat will also provide benefits for many additional species within the ecosystem. Other applications of the technology within lowland tropical forest could include detection of logging, enhancing anti-poaching patrols, and real-time landscape mapping.**

Key Words.—aerial mapping; behavioral ecology; conservation; cryptic; habitat use; nesting; UAV

Introduction

Accurate behavioral monitoring of any species is crucial in the drafting of conservation and management plans (Kleiman et al. 1986). To obtain such data, a wide array of methodologies have been conceived and implemented, each associated with its own set of intrinsic limitations. Direct observations, while effective, may only capture a fraction of behaviors with an associated ongoing risk of behavioral modification through human presence (Bejder et al. 2009). The use of remote, non-invasive, behavioral monitoring provides the key to observing natural behaviors. Technologies, such as camera trapping, can provide insights into some natural behavior, but are restricted to discrete locations. The ability to track animals remotely and continuously with Global Positioning System (GPS) technologies has led to major advances in studies of wildlife behavior and habitat usage, while also providing more accurate home range estimates (Seegar et al. 1996; Hebblewhite and Haydon 2010). Despite these advances, the monitoring of more cryptic, fine scale behaviors remains a challenge.

The use of drones, or unmanned aerial vehicles (UAVs), is a burgeoning facet of conservation biology with the potential to revolutionize the way in which animals and habitats are monitored. Drone technology in itself is not a new development, with military applications having expanded rapidly over the past decade (Vogel 2010). These tools have, however, always been too expensive for scientific application. The development of low-cost, open-sourced alternatives has brought the technology within financial reach of researchers and conservationists, and low-cost aircraft can be purchased and equipped for as little as $2,000 US (Koh and Wich 2012). The open-sourced nature of the technology, coupled with the large online community of hobbyists, as well as professionals, could lead to drone use being a viable staple of conservation biology.

One example of a taxon whose biology and ecology can be much better investigated and understood by applying drone technology is crocodilians. This is particularly so in the detection and mapping of crocodile nesting behavior. Until recently, crocodilian nest studies focusing on location and distribution have used helicopter and airboat surveys both for identification and validation of nest sites (Magnusson et al. 1978; Rice et al. 2000; Harvey and Hill 2003). These techniques are financially costly, despite being more feasible for more remote regions. Walked surveys have, until now, often been used in conjunction with helicopter surveys to find and validate crocodile nesting habits (Harvey and Hill 2003).

Estuarine Crocodiles, *Crocodylus porosus*, are the largest extant crocodilians, with individuals reaching in excess of 6 m in length (Britton et al. 2012). Nesting behavior in *C. porosus* involves females building mounds of both vegetation and mud (Webb et al. 1977). Nests are usually built within 5–10 m of permanent water sources, however, they can be as much as 100 m from deep water (Webb et al. 1977; Harvey and Hill 2003). Work on *C. porosus* nesting has been largely confined to Australia, with a paucity of studies in South East Asia.

As well as being highly labor intensive, there are numerous challenges involved in the surveying of *C. porosus* nests in mixed tropical habitats. Semi-inundated and swamp forests, with tall grass, pose logistical challenges to nest detection efforts, as well as being potentially dangerous obstacles for surveyors. Drone technology provides a logical next step in nesting monitoring methodology, due to relatively low initial cost, repeatability, and flexibility. Here the potential use of such applications is described on *C. porosus* in the Lower Kinabatangan Wildlife Sanctuary (LKWS), Sabah, Malaysia

Materials and Methods

We carried out flights using a fixed-wing drone (Bormatec-MAJA: Bormatec, Mooswiesen, Ravensburg, Germany), with a wingspan of 1.8 m and a weight of 3 kg, comprised largely of expanded polypropylene. The aircraft was capable of bearing a payload of about 500 g. This allowed us to add camera equipment (250 g), as well as maximizing the flight time on a single battery (3S 4,000 mAh). The aircraft was able to make single flights of 23–25 km, or approximately 250 ha, if flown in grid formation, with flights of this distance taking between 30 and 40 min to complete (Fig. 1). We could have extended this range to a maximum of 50–70 km with the use of larger 3S 10,000 mAh batteries, but this would have resulted in a reduction in payload capability.

Our choice of camera (Model S100, Canon, Ota, Tokyo, Japan) used during flights was based on both cost and performance capabilities, the unit was customised with a firmware (a set of instructions stored in ROM Read Only Memory) enhancement created using a Canon Hack

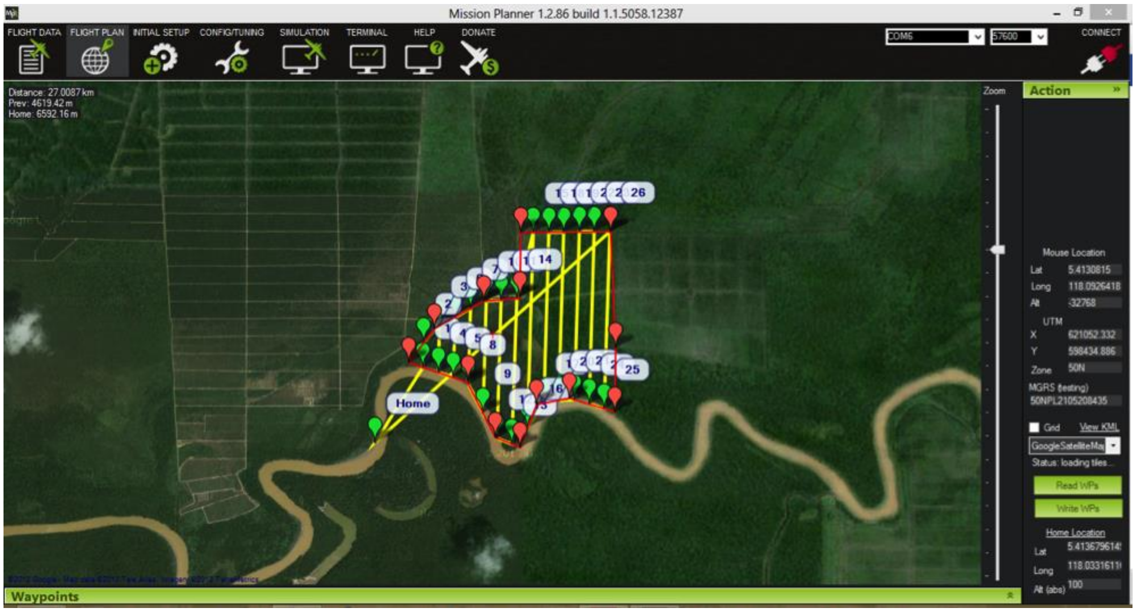

Figure 1. Planning missions using Auto Pilot Module (APM) planning software. Flights were flown in a grid formation with transects separated by a predetermined distance to allow sufficient overlap for stitching. Transect separation was 170 m. The image displays the actual route taken by the unmanned aerial vehicle (UAV) during a single flight covering around 300 ha.

Development Kit (CHDK), which is stored in a camera memory card. A special inter-volameter script was developed by Conservation Drones (www.conservationdrones.org) allowing the camera to take pictures at regular intervals. To provide sufficient picture overlap of about 50%, we calculated the shutter intervals by evaluating drone airspeed and altitude (Koh and Wich 2012). Our flights were planned and uploaded through the Auto Pilot Module APM mission planner, an open sourced ground control station software, in concordance with methods described by Koh and Wich (Fig. 1). We flew transects 170 m apart. This distance was based on the altitude and the resolution of the camera. As the flights were flown at 300 m, we instructed the firmware to take a single picture every 3 sec. This resulted in a picture overlap in excess of 60%.

Flying at 300 m allowed maximum landscape coverage, as well as ensuring good clearance above all tree lines. Also, at this altitude, picture resolution averaged 8–9 cm per pixel. This allowed us to easily detect any potential crocodile nests, which measure 1–2 m in diameter (Webb et al. 1977). We launched the drone manually and flew via remote control until it reached an altitude of about 100 m. Once this height was reached, we switched to auto-pilot, controlled via the mission planner, which ordered the drone to follow predefined coordinates at the cruising altitude. We recorded average drone airspeeds of 40–50 kmph, but this was heavily influenced by wind speed and direction. Greater resolutions of pictures could be achieved, but to attain this would require flying at a lower altitude. When flown at 200 m, flights yielded a resolution of around 5–6 cm per pixel. This resulted in a reduction in aerial coverage per flight of around 26%, given the same payload and battery capabilities. This method can be used, however, when images are not sufficiently clear to identify nesting mounds effectively.

We piloted these missions from 14–18 October 2013, Sabah's wet season; during the nesting season for the region's crocodiles. We flew flights in four key, predetermined areas

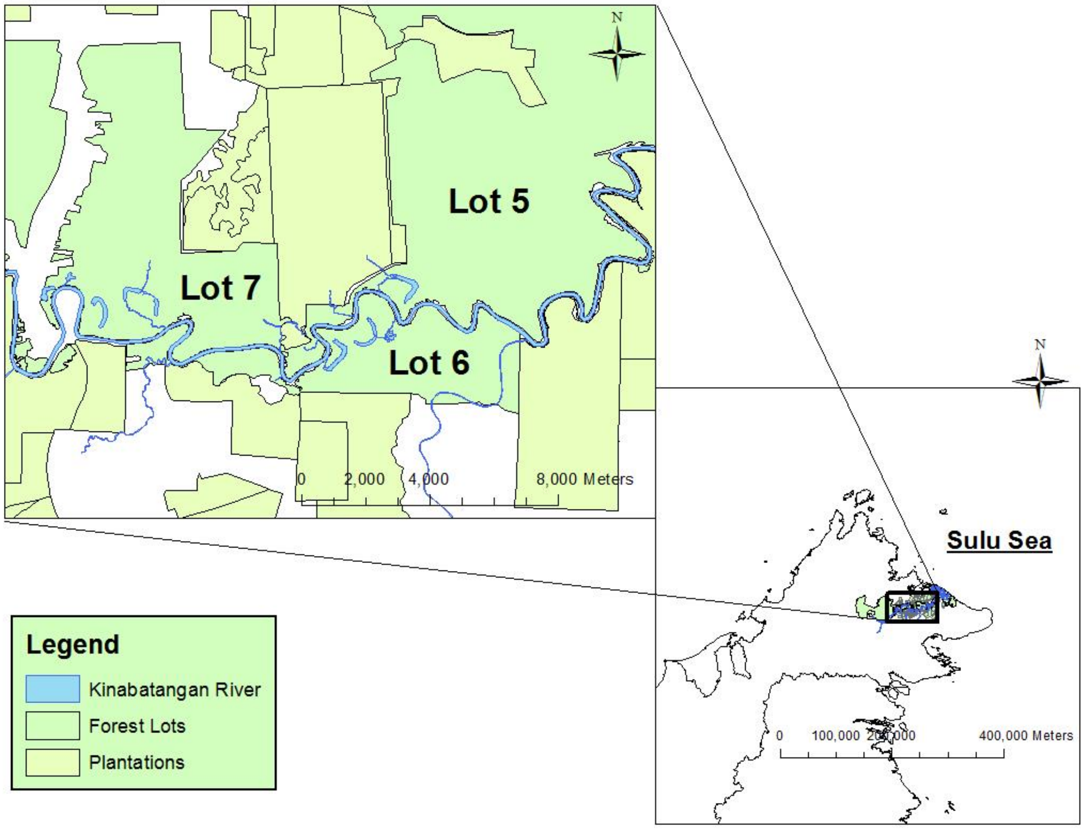

Figure 2. The study site situated in the Lower Kinabatangan Wildlife Sanctuary (LKWS), located within the Malaysian state of Sabah. The survey area comprised parts of Lot 5, 6, and 7.

based on direct observations of both crocodile juvenile prevalence and suitable habitat. Our survey areas covered two of the largest tributaries along the Kinabatangan. Both tributaries are sites of human fatalities from crocodile attacks within the last two years and are subject to direct encroachment from agriculture. We selected two additional areas as characterized by large areas of swamp-land and drying, old oxbow lakes, both excellent crocodile nesting habitat. We timed our flight missions to occur at different times to establish which daylight conditions resulted in the best nest detection and image stitching capability. We conducted flights in early morning (0700–0900), later morning (0900–1100), or afternoon (1400–1600). Once retrieved, we stitched together our images using program Pix4D (Pix4D SA, Lausanne, Switzerland), and the minimum system requirements for this program include an i7 quad core processor along with 32 GB RAM Random Access Memory and an SSD Solid State hard drive.

Our study site consisted of a stretch of the LKWS encompassing Lots 5 (N5.423742°, E118.055597°), 6 (N 5.397137°, E 118.073509°), and 7 (N 5.414195°, E 117.972°; Fig. 2). This region is comprised of a forest-oil palm matrix, located some 150 km from the Sulu Sea in an area with a large and growing crocodile population (Luke Evans, unpubl. data). The nesting of crocodiles in the area has not been studied in detail, although several unsuccessful helicopter surveys have been conducted within the Kinabatangan (Jibius Dausip, pers. comm.). The use of drone technology allowed for the specific targeting of areas deemed suitable for assessment

Figure 3. A) Stitched image of 280 ha fight flown at 0700 local time GMT+8, where the stitching quality was of high. B) Stitched image of 390 ha flight flown at 1400 local time GMT +8, where the stitching quality was of low.

without the need to fly over vast tracks of unsuitable habitat.

Results

We conducted five preliminary flights, assessing areas ranging between 200 and 390 ha in area, resulting in a total survey area of 1,550 ha. We flew three missions at either 0700–0900 or 0900–1100, and an additional two at 1400–1600. Images captured while flying in the 0700–0900 period provided the clearest stitched collages (Fig. 3a), whereas images flown 1000–1500 were more fragmented during the stitching process (Fig. 3b).

We identified nests by searching stitched images and zooming in on specific areas of interest identified from the original images (Figs. 4a and 4b). Following the flight missions, we identified three potential nests. All potential nests were located in the drying remnants of old oxbow lakes. Following detection, we sought to validate the nest site on foot, with care taken to ensure no female presence (Fig. 4c). Of these three, we confirmed two as active nest sites. Both were situated in seasonally flooded areas and were within 150 m of a permanent waterway. One confirmed nest was located just 150 m from a large plantation, within audible range of the plantation. The third, unconfirmed nest was located but found to be an area of dead grass.

Figure 4. A) The raw aerial image of a potential nest (red outline) located in Koyah tributary, one of the largest tributaries of the Kinabatangan River. B) Zoomed image displaying potential nest. C) Confirmed nest found in Koyah tributary. The central mound is surrounded by marshy wallows used by a female. The mound measured 60 cm in height and 1.5 m in diameter.

Discussion

The study confirms that drone technology can be applied to surveys of crocodile nesting. Given this, drone surveys have the potential to become the standard mechanism for crocodile nest detection. The presence of crocodile nests in areas of low to medium levels of human disturbance were confirmed, with one of the nests being identified in close proximity to an oil palm plantation. The study did not set out to assess detection rates. The financial benefits associated with this approach coupled with the ease of repeatability can ensure enhanced understanding of crocodile nesting ecology and lead to long-term monitoring efforts, even in remote locations. Beyond this, the technology could also have considerable impact within the field of behavioral ecology. It must, however, be emphasized that scientific applications of drone technology are still in their infancy. Further improvements in flight time and duration over the coming decade will ensure that many other applications become feasible. During this study, for example, it was possible to detect a recent (about one month old) 5.51 ha forest clearance situated directly adjacent to the LKWS boundary. While legal, such encroaching conversions need monitoring to ensure wildlife sanctuary boundaries are not breached and to maintain remaining forest cover in an already highly fragmented region. This type of monitoring has the potential to alter completely the way in which protected areas are managed, with real-time boundary security a true barrier to illegal logging. Close monitoring such as this can also aid in the understanding of habitat requirements of many species, thus enabling better resource management to sustain the remaining fauna of the region.

One confirmed nest, located roughly 150 m from the edge of a large plantation, was found in a strip of forest currently outside the LKWS boundaries. This, coupled with its close proximity to an existing plantation, makes the area highly susceptible to habitat conversion. The discovery of its use as active crocodile nesting grounds could lead to its subsequent protection. Gaining a change in land protection status can be incredibly challenging; however, the presence of important nesting grounds of any protected species can provide the impetus needed to convince authorities that the status change is warranted. Increases in drone reliability, flight speed, and duration have diversified the applicability of UAVs. The creation of real-time landscape maps, the detection of encroachment and breaching of protected areas, as well as aerial anti-poaching patrols have all become possible as a direct consequence of recent advances in battery capabilities and motor performance. With developing anti-poaching approaches a topic of major conservation importance, the potential of drone technology to contribute to both the monitoring and protection of both highly endangered animals and their habitat is a major possibility.

The ability of drone technology to aid in multiple aspects of both applied conservation and active research have led to its burgeoning prominence in 21st Century science (Estrada and Butler 2012; Koh and Wich 2012). This trend is likely to continue with rapidly improving hardware and firmware. Despite this rapid improvement, many applications do, however, remain unfeasible given current technological limitations. Factors such as component weight versus output is one area that could increase both flight duration and airspeed. Additionally, overall reliability of the major components needs to be improved to give the operator confidence when flying long-range missions. Finally, these improvements must not result in price increases that take the system beyond the financial reach of research and conservation organizations. Future research should focus on quantifying nest detection probability during drone surveys, this will enhance its use both for research and management purposes.

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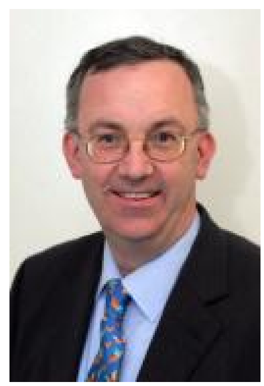

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