



Evaluating the Use of a Quadcopter Drone to Detect Siamese Crocodile (*Crocodylus siamensis*) Nests in Lao PDR, with Incidental Observations of Female Nest Attendance

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The use of unmanned aerial vehicles (UAVs; hereafter drones) is becoming increasingly common in conservation biology and has the potential to revolutionize the way in which wildlife and wildlife habitats are studied (Jones et al. 2006; Koh and Wich 2012; Evans et al. 2015; Hodgson et al. 2018). Crocodylians appear well-suited to drone-facilitated research and monitoring (Scarpa and Piña 2019) and, although still largely experimental, drones have been employed to locate and count nests and identify critical nesting habitat (Evans et al. 2015; Elsey and Trosclair 2016; Evans et al. 2016; Platt et al. 2018a; Scarpa and Piña 2019), count individuals and assess populations (Ezat et al. 2018; Thapa et al. 2018; Aubert et al. 2022; Sawan et al. 2023), capture animals (Brien et al. 2022), and study difficult to observe behaviors in the wild (Bevan et al. 2018). Drones appear to be particularly well-suited for locating and counting crocodile nests (especially mound nests), a task usually carried out at much greater expense using helicopters and fixed-wing aircraft (Magnusson et al. 1978; Bayliss 1987; Rice et al. 2000; Calverley and Downs 2014).

The Siamese Crocodile (*Crocodylus siamensis* Schneider 1801) is a large crocodylian (total length [TL] to 400 cm) that occurs (or formerly occurred) in freshwater habitats throughout mainland Southeast Asia (Thailand, Cambodia, Laos, and Vietnam), and on the Sundaic Islands of Java and Borneo (Platt et al. 2019). Wild populations are now greatly diminished as a result of habitat destruction, commercial hunting for skins, direct persecution because of perceived danger to humans and livestock, and overharvesting to stock crocodile farms (Platt et al. 2019). Consequently, *C. siamensis* is listed as Critically Endangered on the IUCN Red List of Threatened Species and considered one of the most imperiled

crocodylians in the world (Platt et al. 2019). Although many aspects of reproduction among wild *C. siamensis* remain ill-defined and poorly studied, nesting is known to occur during the late dry and early wet seasons (April to June) when females deposit clutches of up to 50 eggs in a large mound constructed of soil, leaf litter, and vegetation (Platt et al. 2019, 2022). Herein we evaluate the use of a drone for detecting *C. siamensis* nests in the wetlands of Lao PDR (hereafter Laos), and report incidental observations of nest attendance by female crocodiles. We broadly define nest attendance as a suite of parental behaviors that includes females maintaining and defending the nest, remaining in close proximity to the nest, opening the nest when eggs hatch, and transporting hatchlings to water (Merchant et al. 2018; Murray et al. 2019).

Our drone survey was conducted as part of an ongoing conservation project that aims to restore a viable population of *C. siamensis* to the Greater Xe Champhone Wetland Complex (GXCWC) in Savannakhet Province (Platt et al. 2014b, 2022). The GXCWC encompasses 45,000 ha of seasonally inundated natural and anthropogenic wetlands, human settlements, agricultural ecosystems, scrubland, and forest, approximately 12,200 ha of which are now designated as the Xe Champhone Ramsar Site. The physical environment, vegetation, and social setting of GXCWC are discussed in greater detail elsewhere (IUCN 2011; Platt et al. 2018c).

As part of our conservation efforts in the GXCWC, we employ locally-recruited Village Conservation Teams (VCTs) to search for *C. siamensis* nests by foot and boat beginning in early May and continuing through late July. VCTs focus on microsites used by nesting females in previous years, and

also search other potential nesting habitat. When a nest is located, VCTs immediately notify us and we travel to the site and collect the clutch, usually within 24 hours. We artificially incubate the eggs and rear the hatchlings at a village facility where the young crocodiles are head-started for approximately 32 months before being transitioned into the wild (Platt et al. 2014b, 2022).

We used a drone to search for crocodile nests at three oxbow lakes (Kout Kouang, Kout Koke, and Kout Mak Pheo) in the GXCWC during July 2022. These lakes are characterized by open water interspersed with thick mats of floating peat that support graminoids (grasses and sedges), shrubs, and small trees (Fig. 1). During June 2022, VCTs initially located four active crocodile nests in Kout Kouang (N = 2), Kout Koke (N = 1), and Kout Mak Pheo (N = 1), and we returned later and collected the eggs (7 and 28 June 2022). When collecting these clutches, we left 1–4 eggs in each mound to appease the nesting female crocodile as per the requests of local people (Platt et al. 2022) who attach supernatural status to crocodiles (Platt et al. 2018b). After collecting the clutch, we then carefully closed the nest and restored the physical structure of the mound.

Our drone surveys were conducted at Kout Kouang and Kout Koke, and Kout Mak Pheo, on 2 and 4 July, respectively. The objectives of our drone survey were three-fold: (1) investigate previously identified active crocodile nest sites to familiarize ourselves with the appearance of nest mounds when viewed from the drone; (2) determine the appropriate altitude to operate our drone when searching for crocodile nests, and (3) search for additional crocodile nests that were overlooked by VCTs during ground surveys in May and June.



Figure 1. Oxbow lake in the Greater Xe Champhone Wetland Complex (GXCWC) of central Laos. Surface of the lake is covered by a mat of floating peat supporting grass, shrubs, and thickets of small trees (bottom right corner). Floating peat mats are important nesting habitat for female Siamese Crocodiles (*Crocodylus siamensis*) in GXCWC. Photograph courtesy of Wildlife Conservation Society–Lao Program.

To accomplish these objectives, we used a quadcopter drone (DJI Mavic 3 Fly More Combo™) equipped with two cameras capable of taking videos and still imagery, both at normal focus and with optical zoom. The drone weighs 895 g (inflight dimensions ca. 350 × 280 × 100 cm), operates on a radio signal from the controller, and is GPS stabilized, allowing it to navigate and fly while taking stable video and photographs even in high winds. The drone has a flight range of 2–7 km, maximum altitude of 500 m, and a normal flight duration of about 35 minutes before batteries must be replaced. The two cameras are mounted beneath the drone on a GPS-stabilized gimble (stabilized independently of the drone). The primary camera is a Hasselblad™ camera with a shutter speed of 8-1/8000 and apertures of f/2.8–f/11, taking 200MP still photos and 5.1K video at 50 frames per second (fps) or 4K video at 120 fps. The secondary telephoto camera has a zoom equivalent to 162 mm (giving an optical zoom of 28 X) with an electronic shutter speed of 2-1/8000 s and aperture of f/4.4. The telephoto camera takes 12MP photos and shoots 4K video at 50 fps. At each oxbow lake, we first flew the drone over previously identified nest sites to examine and photograph nests. Subsequently, we flew the drone slowly over floating mats and along the shoreline scanning for additional nests that might have gone undetected during foot and boat searches conducted by VCTs. We operated the drone at altitudes between 30 and 100 m when searching for crocodile nests.

During our drone survey we successfully relocated the four active crocodile nests previously found during foot and boat surveys conducted by VCTs in Kout Kouang, Kout Koke, and Kout Mak Pheo (Fig. 2). We also located an active crocodile nest in Kout Mak Pheo that had not been previously detected by VCTs (Fig. 3). We returned to this nest on 19 July 2022 and collected 24 of the 28 eggs in the mound for incubation. We initially operated the drone at an altitude of 100 m above-ground, but experienced difficulty in locating the previously identified nests from this altitude despite knowing the specific location of the mounds. We then descended to about 30 m, which was sufficiently high to avoid navigational hazards presented by trees and tall bamboo, yet low enough for us to clearly discern the nest mounds. When viewed from ca. 30 m above-ground, nest mounds were conspicuous, even when partly obscured by trees or shrubs. We also noted that nests were usually surrounded by a disturbed area extending 1–2 m from the mound where females had scraped vegetation and muck into a pile during nest construction (Fig. 3). At two nests found during our earlier foot and boat surveys, trails made by crocodiles through floating vegetation and radiating out from the mound could be clearly seen from the drone, although these trails were not easily discernible to us when on the ground. We observed and photographed crocodiles (presumably the nesting females) in



Figure 2. Siamese Crocodile (*Crocodylus siamensis*) nests photographed from a drone at Kout Kouang (left) and Kout Mak Pheo (right) in July 2022. Note the disturbed area surrounding the mounds where females scraped together vegetation and muck during nest construction. Trails radiating from the nest mound are visible in the right photograph. These nests had been found previously by Village Conservation Teams and the eggs collected for incubation during June 2022. Photographs courtesy of Wildlife Conservation Society–Lao Program.



Figure 3. Siamese Crocodile (*Crocodylus siamensis*) nest photographed from a drone at Kout Mak Pheo that had not been found previously by a Village Conservation Team. The nest is concealed beneath a small shrub (white arrow) and not readily visible from the drone. The area of disturbed vegetation around the shrub and trails around the site provided tell-tale clues that facilitated detection of the nest. Photograph courtesy of Wildlife Conservation Society–Lao Program.

attendance at three (60.0%) of the five nests observed from the drone (Fig. 4). To our knowledge, these are the first photographs of wild *C. siamensis* taken from a drone or other aerial platform. We observed the attending female crocodiles in wallows excavated in the floating peat mat adjacent to the nest mounds. The attending crocodiles exhibited no obvious reaction to the drone hovering above the nests.

Our experience in Laos is similar to the reports of other researchers who employed both fixed-wing (Evans et al. 2015; Platt et al. 2018a; Scarpa and Piña 2019) and

quadcopter drones (Elsley and Trosclair 2016) to successfully search for crocodylian nests. We elected to use a quadcopter rather than a fixed-wing drone for our surveys because the former can be operated at very low altitudes and most importantly, are more maneuverable, allowing us to closely approach a suspected nest and hover overhead while the mound was being inspected and photographed. Fixed-wing drones are generally flown at altitudes of 100–300 m when searching for crocodylian nests and cannot be maneuvered for closer inspection of nests (Evans et al. 2015; Platt et al. 2018a; Scarpa and Piña 2019). However, we were unable to consistently detect nests when operating the drone at altitudes much greater than 30 m. Elsey and Trosclair (2016) flew at considerably lower altitudes of 8–10 m when using a quadcopter drone to search for American Alligator (*Alligator mississippiensis* Daudin 1801) nests in open marsh where tall vegetation was not a navigational hazard. Our operational flight altitude represented a compromise between the need to fly low enough to detect nest mounds while at the same time remaining sufficiently high to avoid trees and clumps of tall bamboo. One advantage of the camera with optical zoom mounted on our drone was the ability to focus on and carefully inspect nest mounds even at this altitude.

Although nest attendance is probably universal among the Crocodylia (Grigg and Kirschner 2015), we are aware of only three previously published reports of this behavior by wild female *C. siamensis*. Kanwatanakid-Savini et al. (2012) found a female concealed in dense grass beside a nest in Thailand that fled from researchers, Bezuijen et al. (2013), stated that a nest in Laos was “fiercely guarded by a female,” and Platt et al. (2020) described an aggressive encounter with a large female at another nest in Laos. Moreover, during visits to 19 different nests to collect eggs for incubation (2019–2022), we encountered only two female *C. siamensis* attending nests; in one case the female aggressively defended her nest, whereas the second female fled upon our approach. The presence of



Figure 4. Female Siamese Crocodiles (*Crocodylus siamensis*) photographed using the zoom camera on the drone. These females are attending active nests at Kout Kouang (left), Kout Koke (center), and Kout Mak Pheo (right) during early July 2022. Photographs courtesy of Wildlife Conservation Society–Lao Program.

female crocodiles at 60% of the nests we inspected during our brief, two-day drone survey strongly suggests that nest-attendance behavior by *C. siamensis* is more commonplace than previously recognized. Our observations of attending females further highlight the value of drones for documenting cryptic and poorly understood behaviors among wildlife (Bogolin et al. 2021).

Drones can potentially disturb wildlife, especially when animals are approached too closely (Aubert et al. 2022). However, the behavioral response of most species to drones remains poorly documented despite this being an important consideration when conducting drone-based studies (Bevan et al. 2018; Bogolin et al. 2021; Aubert et al. 2022). This is particularly true for crocodylians, especially nesting females, which may abandon nests if disturbed (Wilkinson 1983; Elsey and Trosclair 2016; Beauchamp et al. 2018). Auditory and visual cues produced by drones (including the shadow of an overhead drone) can elicit behavioral responses in crocodylians that depend on the flight altitude of the drone, habitat, and individual activity (e.g., basking, swimming, nest guarding, etc.) (Bevan et al. 2018). Our report appears to be only the second description of the behavioral response of nesting female crocodylians to a drone (see also Elsey and Trosclair 2016). Similar to our experience, Elsey and Trosclair (2016) concluded that even a low-flying (8–10 m aboveground) quadcopter drone caused no discernible behavioral reaction by nesting female *A. mississippiensis*.

Drones have several practical advantages over helicopters, the traditional platform used to conduct aerial surveys for crocodylian nests (Magnusson et al. 1978; Bayliss 1987; Rice et al. 2000). First, drones are much cheaper to operate than helicopters. For example, our drone required an initial investment of about US\$3,000, which is roughly the equivalent of three to six hours of helicopter rental in the United States at US\$500–1000/h (Elsey and Trosclair 2016; Rainwater, unpubl. data). A further consideration in our case is that the only helicopters available in Laos belong to the military and cannot normally be chartered for civilian use. Second, drone

mishaps pose little danger to operators or bystanders (Elsey and Trosclair 2016), in contrast to aviation accidents, which can be potentially fatal and are always a concern when using aircraft for wildlife research and management (Sasse 2003). Lastly, drones require very little in the way of routine maintenance to remain operational, whereas frequent and costly maintenance is necessary if helicopters are to remain flight-worthy. The only major drawback when substituting drones for helicopters in crocodylian nest surveys is the relatively brief battery life and greatly reduced range of drones (< 10 km) in comparison to helicopters (>100 km).

In conclusion, our pilot study suggests that quadcopter drones are a suitable, cost-effective, and safe technology for detecting *C. siamensis* nests in GXCWC. Active nest mounds are conspicuous from low altitudes, even when partly obscured by vegetation. Of the nine active crocodile nests we found during foot and boat surveys at wetlands throughout the GXCWC (Kout Kouang, Kout Koke, Kout Mak Pheo, Kout Jek, Taloung Reservoir, Nong Wai, and Xe Hauk) in 2022 (Platt et al. 2022), seven (77.7%) were constructed on open, floating peat mats and would likely be visible from a drone, whereas the remaining two (22.2%) nests were concealed within dense bamboo and vine thickets and therefore unlikely to be detectable from the air. That said, the experience of one of us (LDM) when using drones to search for *A. mississippiensis* nests, suggests that the heat signature generated by decomposing vegetation incorporated into the mound might be detectable with a thermal-imaging camera (e.g., Bushaw et al. 2020) even when a nest is concealed by dense, overhead vegetative cover. Importantly, our pilot study indicated that nesting female *C. siamensis* seem to pay little attention to brief overhead visits by a quadcopter drone. Given the limitations of nocturnal spotlight counts, camera trapping, and scat and sign surveys (see Platt et al. 2014a), annual nest counts are considered the most appropriate methodology for monitoring long-term population trajectories of *C. siamensis* recovery in the GXCWC (Platt 2021). To this end, we will henceforth augment the foot and boat searches conducted by

VCTs with drone surveys to improve the resolution of our estimate of annual crocodile nesting effort in GXCWC.

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