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Employing Camera Traps for Studying Habitat Use by Crocodiles in a Mangrove Forest in Sarawak, Borneo

Effective wildlife monitoring for conservation relies on census methods that deliver cost effective and logistically efficient data. Camera trapping has become a common tool in contemporary wildlife science, helping researchers collect images of uncommon or rarely seen and often threatened species as evidence. The development of camera trapping technique has led to significant advancement of the understanding of the diversity of animals and has helped detect secretive species that survive in low densities (e.g., Mohd-Azlan 2003; Mohd-Azlan et al. 2003). However, relatively few studies of crocodilians have employed the technique (Thorbjarnarson et al. 2000; Channa et al. 2010; Charruau and Hénaut 2012; Platt et al. 2014a), and one recent survey reported a lack of success (Platt et al. 2014b), possibly due to lack of technical modification of motion-sensitive infrared cameras (Merchant et al. 2012).

Camera traps are designed purposely to detect wild animals by using a passive infrared sensor (Mohd-Azlan and Engkamat 2006). The camera incorporates a mechanism to trigger a photograph by the movement and differential heat of the main subject in front of the camera and that of its surroundings. Additionally, the use of camera traps can reduce bias in data, such as in wildlife surveys, which can have an adverse effect on the results (Mohd-Azlan 2009). Another advantage of the technique is that it is non-invasive, not involving handling of target species (Ancrenaz et al. 2012; Ariefiandy et al. 2013; Sunarto et al. 2013).

Although primarily aquatic, crocodilians typically require terrestrial substrate, such as mud flats and water-edge environments for activities, including nesting, foraging (for terrestrial animals, such as pigs, primates, and otters), or thermoregulatory purposes. They can move considerable distances both overland (Pooley and Gans 1976) and along waterways (Walsh and Whitehead 1993).

In this study, we analyze crocodile activity and terrestrial habitat use in the vicinity of river banks with the use of camera traps, in order to increase understanding of crocodile behavior. These objectives are relevant given the escalating levels of human-crocodile conflicts in Sarawak (Das 2002). Thus, by setting up camera traps at selected areas where Saltwater Crocodiles are believed to habitually land, more information on their activity patterns can be obtained. The general objectives of the current study were to test whether camera traps can be used to record timing of activities and habitat use of crocodiles.

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Methods

We conducted this study at Pulau Liak in Kuching Wetland National Park (KWNP; Fig. 1), located ca. 8 km SW of Kuching City, the capital of Sarawak State, in East Malaysia (Borneo) where the Saltwater Crocodile (*Crocodylus porosus*) is listed under Part II of the First Schedule of the Sarawak Wild Life Protection Ordinance 1998. KWNP consists of coastal, marine, and freshwater ecosystems, and was gazetted as a National Park in 2002. The 6610-ha area is dominated by saline and deltaic mangrove systems, including marine waterways and tidal creeks, such as connecting rivers of Sungei Sibu-Laut, Batang Salak, and Sungei Santubong. The study area was selected to set camera traps centered around Pulau Liak (1.624°N, 110.25876°E; WGS84), and Sungei Sibu (1.676611°N, 110.23666°E), based on previous frequent sightings of *C. porosus* and the presence of crocodile wallows on river banks. Within the KWNP area, the common mangroves are *Rhizophora apiculata*, *Avicennia alba*, *A. marina*, *Bruguiera cylindrica*, *B. sexangula*, *B. gymnorhiza*, and *Ceriops tagal*.

We deployed three units of commercially made passive infrared Bushnell® Trophy Cam Camo-119445 cameras, with sensor resolution of 5MP, which captured images when triggered by movement and/or differences in temperature in the area immediately in front of the camera sensors. Each of these were established at a subsite within the study area (referred to as CT1, CT2, and CT3). Cameras were set with a delay mechanism of three minutes between photographs to reduce repeat photographs of the same individual crocodile. The study period was June 2013 to April 2014, a period of 11 months.

Time periods were analyzed to determine presence of crocodiles and temporal and spatial aspects of activity. To estimate the number of individuals recorded at the same locality, individuals were identified on the basis of both characteristic marks (such as scar tissue on head and body) and an estimation of body size. The activity pattern in terms of landing and functions of terrestrial habitat was also examined. The levels of activity were determined from the date and time recorded on the photograph.

Results

A total of 55 wildlife photographs of four species were recorded from 207 camera days. This includes a total of 43 images of *C. porosus*, including two of hatchlings that suggest the presence of a nest in the study area during the time of survey (November). Additionally, the cameras captured eight images of the Long-tailed Macaque (*Macaca fascicularis*), three images of Oriental Small-clawed Otter (*Aonyx cinerea*), and a single image of an unidentified species of squirrel (Table 1).

Table 1. Photo trap index of animals recorded by camera traps at Kuching Wetland National Park, Sarawak, Malaysia. Abbreviations: IUCN, International Union for Conservation of Nature 2016; LC, Least Concern; VU, Vulnerable; SWLPO, Sarawak Wildlife Protection Ordinance 1998; WCA, Wildlife Conservation Act 2010; CITES, Convention on International Trade in Endangered Species of Wild Flora and Fauna 2013 (listing for Sarawak population); NL, Not Listed.

Order/ Family	Species	Common name	Total images	IUCN	SWLPO	WCA	CITES
Crocodylia							
Crocodylidae	*Crocodylus porosus*	Saltwater Crocodile	43	LC	Part II	Schedule I; Part 2	II
Primate							
Cercopithecidae	*Macaca fascicularis*	Long-tailed Macaque	8	LC	Part II	Schedule I; Part 2	NL
Carnivora							
Mustelidae	*Aonyx cinerea*	Oriental Small-clawed Otter	3	VU	Part II	Schedule I; Part 2	NL
Rodentia							
Sciuridae	unknown	Squirrel	1	–	–	–	–
Total			55				

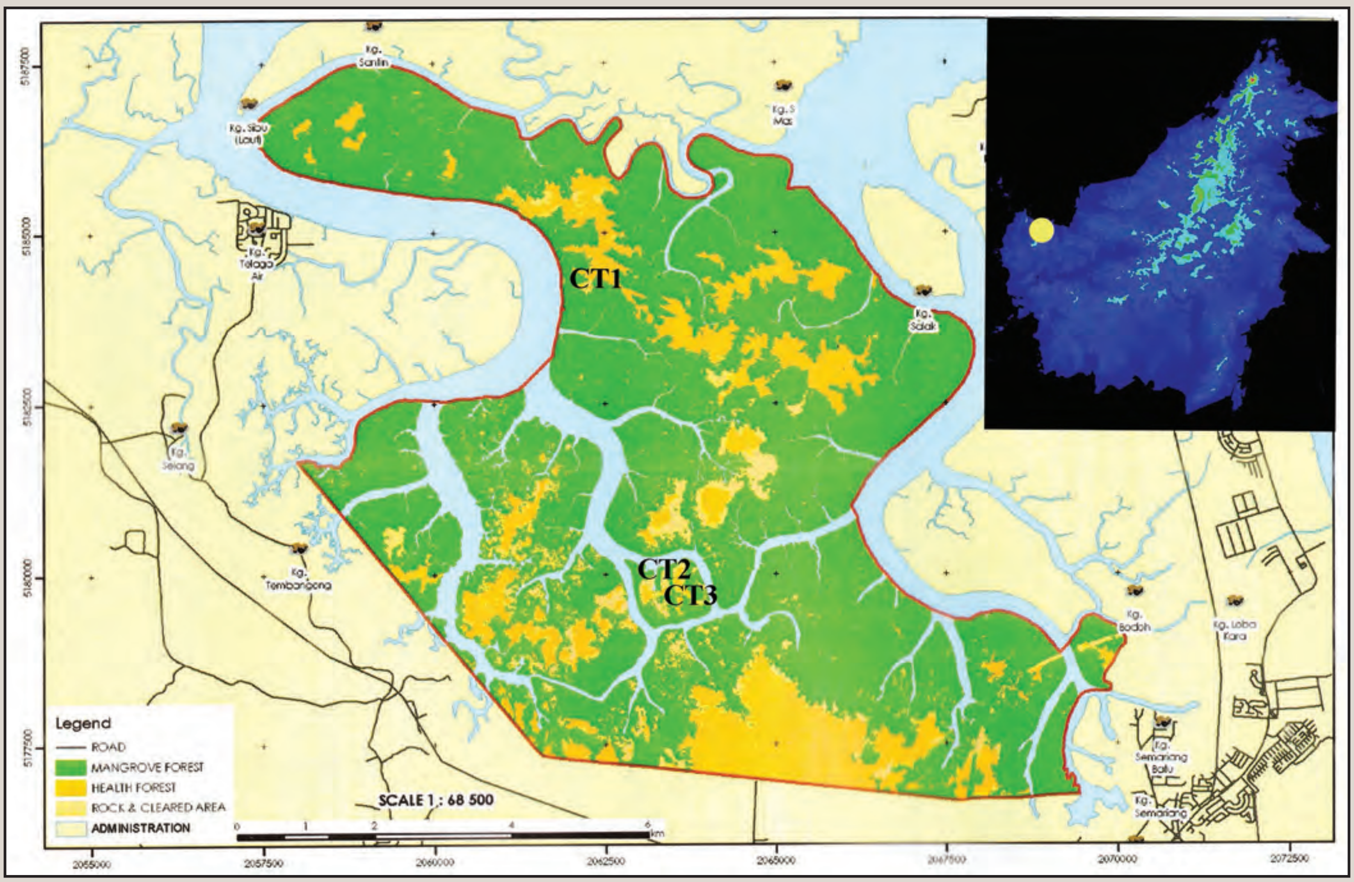

Fig. 1. Map of Kuching Wetland National Park, dominated by mangrove habitats, with islands of secondary forests. Three camera trapping sites are indicated (CT 1–3). Locator map of Borneo on top right, showing location of study site (yellow dot).

Of the total images captured, 91% were taken after dark (1800–0800 h) and four (9%) recorded during daylight hours (Fig. 2). The terrestrial activity pattern of *C. porosus* shows that their presence near riverbanks peaked during 0400–0500 h (N = 8), and they tend to be present around specific sites for 30–60 mins. This suggests that peak activity occurs just before dawn, at ca. 0630 h. No photographs were captured between 0500–0600 h, 0800–1100 h, 1300–1400 h, and 1600–1800 h, suggesting that the heavy human activities in the area, such as the operation of fishing boats near the banks, might reduce landing activities of crocodiles. Although a greater number of crocodiles were recorded during high tide than other tidal conditions (Fig. 3), our data are insufficient to correlate crocodile emergence with tidal conditions. Images of eight individuals were captured during incoming high tide and two during low tide, between 1900–2000 h and 0600–0700 h, respectively.

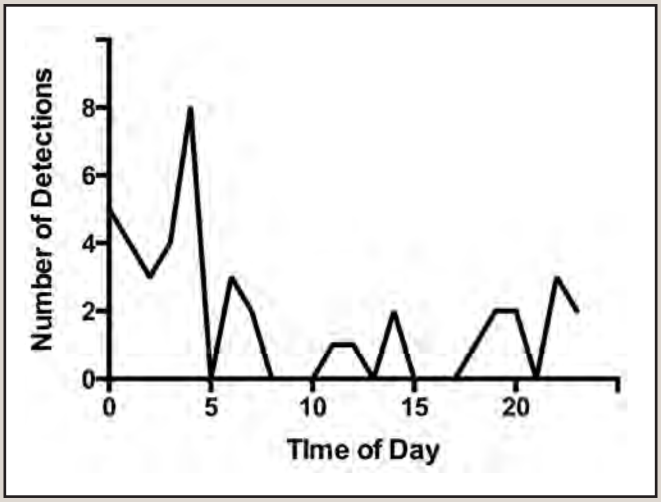

Fig. 2. Activity levels of *Crocodylus porosus*, showing peak activity during dawn and dusk, with sporadic activities during daylight, based on camera trapping data. Time of day: 0000 h to 2400 h.

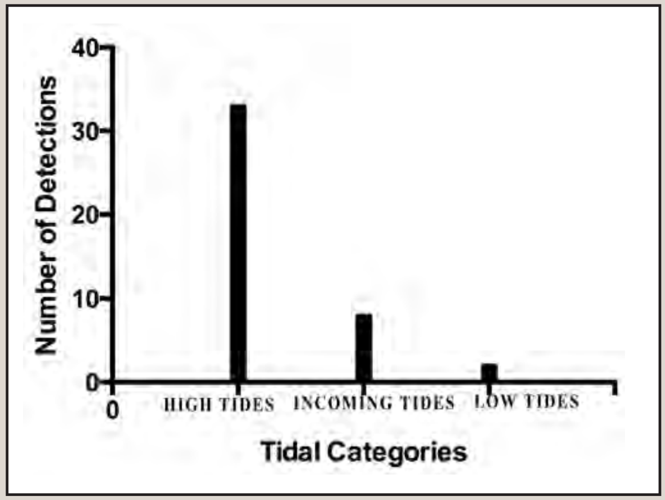

Fig. 3. Number of images of *Crocodylus porosus* captured related to tidal condition, showing approximately 77% of images coincided with high tide.

From the image analysis, at least four individual crocodiles were confirmed as residents (Fig. 4). Four images captured only the eyes of the crocodiles, whereas eight images were of tail only. However, based on estimates of size of the crocodiles, these images are believed to represent the only two individuals.

Discussion

Numerous studies have demonstrated the efficacy of camera traps in the study of medium to large-sized mammals and birds (Rovero et al. 2010 ; O'Connell et al. 2011; Meek and Pittet 2012), small mammals (Oliveira-Santos et al. 2008), large mammals (Mohd Azlan and Sharma 2006), crocodilians (Chowfin and Leslie 2014), large lizards (Ariefiandy et al. 2013), and amphibians (Pagnucco et al. 2011). Camera traps have also been successfully deployed for studying critical life history events, including aggregation around mineral licks (Matsubayashi et al. 2007), predation (Campos and Mourão 2014), and nest care (Charruau and Hénaut 2012).

The present study corroborates Huchzermeyer's (2003) classification of crocodiles as nocturnal, with active foraging done at night, while opportunistically feeding by day. *Crocodylus porosus* was mostly recorded in the vicinity of the riverbanks, during dusk, night, or dawn. By this time, water temperature is warmer than the land on account of the absence of radiation. Ectothermic animals tend to move from a relatively cool to a warm environment and increase their heart rate to raise heat convection and cooling rates (Franklin and Seebacher 2003). In addition, crocodile activities in terrestrial habitats may be correlated with local tidal conditions. Most images captured were during high tide (≥ 3.0 m). In spite of the fact that crocodiles prefer to stay near riverbanks during high tides or incoming tides, macaques and otters (both potential prey of crocodiles) are active during low tide, probably to use mangroves as an extension of their terrestrial habitats and to forage for food on the mud flats during low tide. Mud crabs are among the favorite food of the Long-tailed Macaques, and perhaps also of otters.

At least four individual crocodiles are confirmed to be residents within the area where the CT1 camera was set, based on size and cephalic markings observed. *Crocodylus porosus* is known to maintain territories or home ranges (Pope 1955). Three photos of adult crocodiles demonstrated reaction to the red flash, by opening their mouths, which may be a common reaction to threat. The reaction by wild crocodiles towards light from camera traps has apparently never been documented in previous studies.

Fig. 4A–B. Photos captured of two individuals of *Crocodylus porosus* at CT2.

The occurrence of hatchlings in November suggests that the breeding season for the species within the area is likely around August. The species is known to nest between November and April (Webb and Manolis 2009; Webb et al. 2010), and September through February is the wet season for East Malaysia due to passage of the Northeast Monsoons. The images of hatchlings provide evidence that the nests are not far, as hatchlings can travel only ca. 50 m from their nesting sites (Webb and Manolis 2009). Pulau Liak (also known as Pulau Buaya, in Malay, "Crocodile Island") can be categorized or identified as one of the nesting sites of the species within the park due to presence of hatchlings and yearlings around that area (Tuen et al. 2010).

Several limitations were encountered in the use of passive infrared sensor traps to study crocodiles. Most cameras have a differential temperature between the target and ambient temperature greater than 2.7°C. Therefore, the passive infrared sensor fails to trigger if the subject in front of the camera has either a low differential temperature or is within the ambient temperature range. Additionally, the passive infrared sensor is case sensitive, and can also be triggered by the movement of hot air or by movement of vegetation within the detection zone (Rovero et al. 2013). Finally, camera locations were restricted to areas that are not inundated, and within the context of this study within a mangrove / tidal region, was dependent on tide levels.

Nonetheless, camera traps show encouraging results. Refinements are required for incorporating the use of cameras in studies of wild crocodilian populations, including: 1) choice of cameras and sampling rate (e.g., brand and specification, that potentially influence detection success rate and memory capacity); 2) placement of cameras (e.g., height, angle, attachment site, and distance from river banks and other potential crocodile habitats, for which experience of field personnel is important); 3) density of cameras in the field; and 4) data collection protocols and analyses.

This study reiterates that camera traps can be used to study wild crocodiles by recording their activity patterns and habitat use at crocodile landing areas without the use of bait. We also show that crocodiles can usually be observed at their landing areas mostly during the night. Both physiology and tides could be factors that affect the presence and movement of crocodiles in the vicinity of riverbanks. Individual recognition can also enhance accuracy of population estimation, using the capture-recapture method.

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Repeatability of Locomotor Endurance in the Small-mouthed Salamander, *Ambystoma texanum*

Amphibian population declines have been linked to a variety of factors, including climate change and habitat destruction (Kiesecker et al. 2001), making assessment of the viability of habitat corridors and assisted dispersal a priority for conservation research (Milanovich et al. 2010). To quantify and evaluate dispersal ability, researchers commonly conduct physiological experiments involving multiple trials on wild-caught specimens. The performance of individuals during these experiments is assumed to be consistent and repeatable, but a direct assessment of whether or not this is the case is lacking. Assessing the value of laboratory experiments for describing performance in nature and for quantifying physiological measures for individuals requires knowledge of the impacts of experimental conditions on these measures (Bennett 1987).

Dispersal in *Ambystoma* salamanders is one case where repeatability of lab-based measurements of locomotor endurance is important because such experiments are used to infer how salamanders move across landscapes. Endurance measures can be combined with a measure of vagility to predict the genetic framework of amphibian metapopulations, as increased endurance and vagility have been shown to decrease genetic heterogeneity between populations (Johnson et al. 2010; Hillman et al. 2014). However, information pertaining to the repeatability of endurance is scarce. One of the very few studies to investigate this matter found that locomotor endurance of the endangered California Tiger Salamander (*Ambystoma californiense*) is repeatable over a period of a few days but not over a longer period of fifteen months (Austin and Shaffer 1992).

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However, this estimation of repeatability may not be generalizable to other salamander species for several reasons. First, *A. californiense* is an endangered habitat specialist found only in Pacific coastal grasslands and is also one of the largest *Ambystoma* species (Trenham et al. 2000). Because surface area plays a major role in the regulation of body temperature and respiration of amphibians, it is difficult to scale the physiology of salamanders of vastly different sizes (Pincheira-Donoso et al. 2008). Second, multiple trial experiments on wild-caught and lab-raised salamanders may occur over a period that falls between just a few days and 15 months in order to measure average performance at a given time point or life-stage, but data on the repeatability of endurance in these time spans is currently lacking.

Common factors associated with the basic housing and care of animals, such as the frequency of feeding prior to trials, might also influence performance. The effects of food quantity on locomotor performance are unclear and other research has rarely taken into account unique aspects of the physiology of the species being studied, such as the remarkably slow metabolisms of salamanders compared to other vertebrates (Feder 1976). For example, feeding can decrease the burst speed of Garter Snakes (*Thamnophis elegans*; Garland and Arnold 1983) or not affect performance at all (Ford and Shuttlesworth 1986). In Trinket Snakes (*Elaphe helena*), large meals limit both burst speed and endurance (Mehta 2006). While an optimal meal size that maximizes endurance and antipredator behavior has been identified in these wild snakes, an optimal meal size or feeding schedule for captive amphibians participating in physiological trials has not been investigated (Sih and Christensen 2001). If we wish to maximize consistency in future experiments involving amphibians that will likely require feeding, we must determine how feeding affects amphibian performance and optimize our research protocol accordingly.