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HIGH SPEED BOAT TRAFFIC: A RISK TO CROCODILIAN POPULATIONS

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***Abstract.*—Injuries related to boat traffic have been documented as a major source of human-related injuries and deaths in many aquatic species but have not been documented in crocodilians. We examined the proportion of boat-related injuries in Spectacled Caiman (*Caiman crocodilus fuscus*) in the Tortuguero region of Costa Rica within waterways with enforced speed limits and those without. No boat injuries were documented in waterways with speed limits; however, in waterways without speed limits, 36.6% of caimans we captured retained old scars or fresh lacerations related to boat propellers, including two mortalities. Presence of enforced speed zones was positively associated with lower rates of collisions, boat propeller related injuries, and mortalities. Slower boat speed may provide sufficient time for caimans to avoid oncoming boats. Increasing boat traffic in the region due to increasing ecotourism and a rapidly expanding local community may increase the vulnerability of this crocodilian species to boat related injuries and population reduction. Imposing enforced speed limits within non-essential transportation routes is a reasonable mitigation measure to help protect this species.**

Key Words.—Boat traffic; *Caiman crocodilus fuscus*; conservation; Costa Rica; Human-wildlife conflicts; injuries; mortality; Tortuguero

INTRODUCTION

Anthropogenic impacts on wildlife populations through habitat loss or pollution are widely recognized. Yet, aquatic wildlife populations can face additional pressure in the form of boat traffic in areas that overlap with human populations. Disturbance to individual animals caused by boat traffic can have non-lethal effects on behavior and reproductive success of animals and result in increased mortality rates (Hodgson and Marsh 2007; US Fish and Wildlife Service Jacksonville Field Office. 2009. West Indian Manatee [*Trichechus manatu]* Florida stock [Florida subspecies, *Trichechus manatus latirostris*] Available from: USFWS Jacksonville Field Office, Jacksonville, Florida 32256. Available from http://www.fws.gov/northflorida/Manatee/SARS/20091230_rpt_Final_Florida_Manatee_SAR.pdf). If the costs of avoiding a disturbance are more than the benefit of remaining in an area, then populations may become displaced (Hodgson and Marsh 2007). Often however, suitable habitat is not available, thereby forcing animals to tolerate the disturbance and reducing fitness (Williams et al. 2006; Hodgson and Marsh 2007). In the case of Killer Whales (*Orcinus orca*), boat disturbance resulted in an 18% decrease in energy intake in conjunction with an increased energy demand as a result of altered behavior (Williams et al. 2006). Altered behavior due to boat traffic disturbance has also been widely reported in numerous species such as Dugongs (*Dugong dugon*; Anderson 1982), Killer Whales (Kruse 1991), Sperm Whales (*Physeter macrocephalus*; Gordon et al. 1992), Delphinidae (Lusseau 2003; Constantine et al. 2004), Manatees (*Trichechus manatus latirostris*; Nowacek et al. 2004), and Marbled Murrelets (*Brachyramphus marmoratus*; Bellefleur et al. 2009), to list a few.

Non-lethal injuries caused by boat propellers are frequent in aquatic animals such as Whale Sharks (*Rhincodon typus*; Speed et al. 2008), Bottlenose Dolphins (*Tursiops truncatus*; Wells and Scott 1997), Killer Whales (Visser 1999), Manatees (Langtimm et al. 1998), and Diamondback Terrapins (*Malaclemys terrapin*; Shaffer 2008), but so far have not been reported to occur in crocodilians. Non-lethal injuries, depending on the severity, reduce fitness and carry a metabolic cost that can negatively affect an individual's reproductive success (Langtimm et al. 1998). Mortality related to boat traffic, a significant impairment to reproductive success, can render populations susceptible to decline or extinction (Langtimm et al. 1998). For example, in the case of Florida Manatees, boat traffic accounts for 30% of documented mortalities (Nowacek et al. 2004; US Fish and Wildlife Service Jacksonville Field Office. 2009, *op cit*). This trend emphasizes a clear need to mitigate boat traffic impact on aquatic populations. Sufficient evasion time allows aquatic animals to avoid approaching vessels (Nowacek et al. 2004). Establishing boat speed limits in critical areas has been effective in reducing collisions, boat propeller injuries, and mortality by giving animals sufficient time to evade approaching boats (Laist and Shaw 2006).

FIGURE 1. *Caiman crocodilus fuscus*. (Photographed by Paul B.C. Grant)

The northern Atlantic Zone of Costa Rica contains a significant wilderness area with numerous interconnected waterways that provide critical habitat for two crocodilian species: Spectacled Caiman (*Caiman crocodilus fuscus*; Fig. 1.) and American Crocodile (*Crocodylus acutus*). Despite their range of occupancy extending into the Tortuguero National Park and the Barra del Colorado Wildlife Refuge, both species still face population pressures from hunting, environmental degradation, and increasing boat traffic due to growing ecotourism in the region. *Caiman crocodilus*, which are much more common than *C. acutus* in this region, is widespread throughout Central America, ranges far into South America, and has been introduced into southern Florida (Leenders 2001). Most adult individuals have a total length of 1.25–2.50 m (Leenders 2001). Of concern is that *C. crocodilus* habitats currently overlap with areas of high boat traffic, potentially impacting their survival. Within the Tortuguero National Park, ecotourism operators offer guided boat tours of its canals, where strict speed limits (idle-slow) are in place. Outside of this small area of protected canals no speed limits are enforced and boats frequently travel at high rates of speed (40 km/h), even within narrow, winding waterways. We caught *C. crocodilus* in waterways in and near the Barra del Colorado Wildlife Refuge and the Tortuguero National Park of Costa Rica. We tested whether the occurrence of boat-inflicted injuries on *C. crocodilus* populations was greater within canals without enforced speed limits than in those with speed limits.

MATERIALS AND METHODS

We conducted this study in the Suerte River basin (10º25'–10º38'N and 83º30'–83º45'W) in the northern Atlantic lowlands of Limon Province, Costa Rica (Fig 2.). This region receives 5,000–6,000 mm of rain per year, and monthly average temperatures range from 22° C to 31° C. We sampled from April-June 2006 within waterways with enforced speed limits (Rio Tortuguero, Cano Mora, and Cano Chiquero) and waterways where speed limits are not enforced (Rio Suerte, Cano Palma, and Cano Penitencia; Fig 2.).

Within these selected waterways, we caught *C. crocodilus* to check for scars and injuries from boat propellers. We captured only adult *C. crocodilus* that were 1.0–2.5 m total length. Because adults are highly territorial, we assumed any injuries sustained occurred within the waterways in which the individuals were caught (Garrick and Lang 1977). We also recorded any caiman mortalities from boat propellers, along with their location, over the study period.

We captured caiman at night from a boat following methods described in Chabreck (1966) and Webb et al. (1990). We individually marked capture animals by removing scutes so that we did not recount recaptured animals. Animals were assessed for boat traffic-related injuries, such as scarring from boat propellers, and released within 20 min of capture. We used a 2x2 Chi-square analysis with Fisher's exact test to compare frequency and percentage of total injured and non-injured individuals between waterways with and without speed limits. We used $\alpha = 0.05$ to assess statistical significance.

RESULTS

We captured 54 *C. crocodilus* that we examined for scars (Table 1). *Caiman crocodilus* were extremely

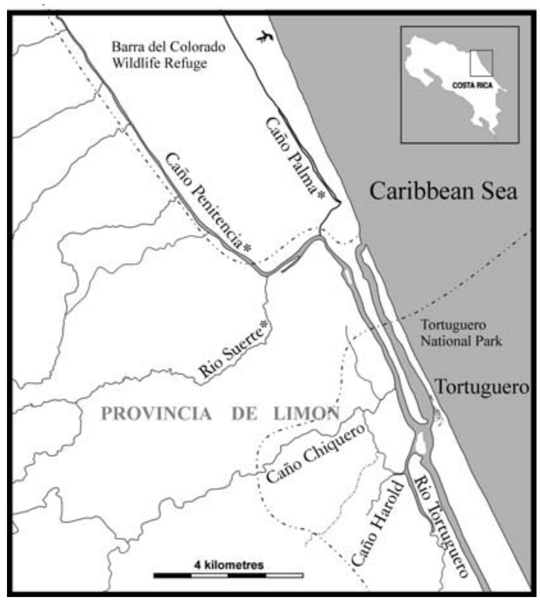

FIGURE 2. Map of the study area showing selected waterways where sampling occurred. Asterisks (*) indicate waterways without speed limits. The approximate boundaries of the Barra del Colorado Wildlife Refuge and the Tortuguero National Park are also shown.

TABLE 1. Chi-square analysis with Fisher's exact test, displaying frequency and percentage (parentheses) of total of injured and non-injured *Caiman crocodilus* individuals within waterways with enforced speed limits and without in Limon Provence, Costa Rica.

	Non-Injured	Injured	Total
Speed Limits	24 (44.4)	0 (0.0)	24 (44.4)
No Speed Limits	19 (35.2)	11 (20.4)	30 (55.6)
Total	43 (79.6)	11 (20.4)	54
Fisher exact *p*, one tailed: *P* = 0.0006			

wary of boats and spot lights in this region, making capture of individuals exceptionally difficult. Within waterways with enforced speed limits, we captured 24 adult *C. crocodilus*; two within Rio Tortuguero, 13 within Cano Mora, and nine within Cano Chiquero (Fig. 2). None of these had any visual sign of injuries resulting from boat propellers. The number of injured individuals was significantly greater within waterways without enforced speed limits (*P* = 0.006). Of the 30 individuals we caught within waterways without speed limits, 11 (36.6%) had obvious boat-related injuries. Of these caiman, we captured 11 within Cano Penitencia (one injured), five within Rio Suerte (four injured), and 14 within Cano Palma (six injured). We found injuries on a combination of areas including the head (one individual), on the dorsal (five individuals) and lateral sides of the body (three individuals), and on the rear legs and tail (six individuals). Injuries included extensive scarring and recent, open, deep lacerations in two individuals; these scars consisted of multiple cuts that were parallel and evenly spaced, similar to reported propeller injuries in other animals (Wells and Scott 1997). We recorded two mortalities, one from Cano Palma, the other from Rio Suerte, and we included these with the number of injured individuals.

DISCUSSION

The Rio Tortuguero, Cano Mora, and Cano Chiquero are within the Tortuguero National Park, where speed limits are strictly enforced. Within these protected waterways, no injured *C. crocodilus* were found. However, 36.6% of all *C. crocodilus* caught within waterways with no enforced speed limits (Rio Suerte, Cano Palma, and the Cano Penitencia) had boat propeller-related injuries. Because adult crocodilians are territorial, we assume that injuries occurred within the respective waterways in which they were captured. Because no injured animals were caught within waterways with enforced speed limits, it is likely that the presence of enforced speed limits was a major factor in the lower number of collisions and boat propeller-related injuries and mortalities. This trend is similar to that reported for other aquatic animals (Laist and Shaw 2006).

Responding to disturbances, such as boat traffic, directly affects survival and reproductive success of aquatic animals through collision avoidance and indirectly through trade-offs between perceived risk and energy intake and expenditure (Frid and Dill 2002; Williams et al. 2006). Habituation to, and underestimation of, threats increases the risk of injury or mortality (Stone and Yoshinaga 2000). *Caiman crocodilus* were frequently observed avoiding oncoming boats, a response that may be due in part to avoiding anthropogenic threats such as hunting, as well as avoiding boat collisions.

Increasing boat traffic in the region due to increasing ecotourism and a rapidly expanding local community can only increase the vulnerability of this species to injury and population reduction. In addition to increased boat traffic, engine size and boat speed has also increased dramatically. Ten years ago engine size ranged between 5 and 25 HP, whereas currently they are between 150 and 250 HP (Mario Gomez, 2001, pers. comm.). Engine noise has also been reduced greatly in modern 4-stroke engine designs compared to older 2-stroke engines, potentially giving *C. crocodilus* less response time. Often, these waterways are extremely narrow and have frequent bends, giving little time for crocodilians to respond and evade fast-moving boats. Diving into deeper water can be a temporary refuge and vertical avoidance of boats is a strategy employed by

FIGURE 3. Typical habitat of *Caiman crocodilus fuscus* at Cano Palma, Tortuguero, Costa Rica. (Photographed by Paul B.C. Grant)

many aquatic animals (Nowacek et al. 2004; Hodgson and Marsh 2007). Frequently we recorded propeller scars on rear legs and tail, indicating that injuries possibly occurred during attempted boat evasion. Boat strike has been identified as a major conservation problem for many aquatic animals, even those that are fast swimmers and have superior manoeuvring abilities such as dolphins (Wells and Scott 1997; Smethurst and Nietschmann 1999; Laist and Shaw 2006). The long-term effect of these injuries is unknown and would vary depending on the severity of the wounds. It is likely that *C. crocodilus* could recover from minor lacerations as evidenced by propeller scars found on several of our captures and because crocodilians exhibit remarkable immune systems with a high degree of resistance to microbial infection (Preecharram et al. 2008).

Within the Tortuguero region, boats are the dominant mode of transportation. The Rio Suerte and Cano Penetencia are important transport routes, whereas Cano Palma has frequent high-speed boat traffic from hotels up-stream and is extremely narrow with numerous small bends that limit vision for both aquatic animals and boat captains. This likely contributes to reducing the amount of time in which caiman can respond to boats. Comparatively, Cano Penetencia, unlike the rest of the waterways sampled, was relatively wide with long straight passages, possibly allowing sufficient response time and space for *C. crocodilus* to avoid boats. Rio Suerte is an essential transport route into Tortuguero and falls outside the protection of the Tortuguero National Park and the Barra del Colorado Wildlife Refuge. Therefore, imposition and enforcement of speed restrictions along this waterway would be impractical. However, Cano Palma falls within the protection of the Barra del Colorado Wildlife Refuge and is important habitat for *C. crocodilus*. Therefore, we strongly recommend that park authorities enforce speed limits along this waterway to reduce boat related injuries and mortalities to *C. crocodilus* and likely to other aquatic animals. Furthermore, we recommend setting up a long-term monitoring plan to monitor the status of crocodilians and measure the effectiveness of enforced speed limits.

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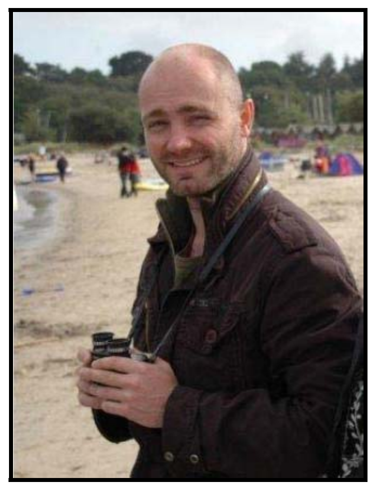

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