An American Crocodile (*Crocodylus acutus*), total lengh 2.3 m, spotted during nocturnal eyeshine surveys in Caye Caulker, Belize. Past exploitation of *C. acutus* led to severe population declines in Belize, but effective management and conservation efforts on Caye Caulker, in association with community outreach, has resulted in a stable crocodile population. © Miriam Boucher

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Population status of the American Crocodile (*Crocodylus acutus*) in Caye Caulker, Belize

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Abstract: We assessed the population status of the American Crocodile (*Crocodylus acutus*) via nocturnal eyeshine and capture investigations in January, March, and April of 2016 in Caye Caulker, Belize. We encountered 55 crocodiles along a 22.15 km survey route. The majority of crocodiles occupied coastal mangrove habitat in the southern (more developed) and northern (less developed) regions of the island. The *C. acutus* population was composed of 36% juveniles, 40% subadults, 16% adults, and 7% were identified as eyeshine only (encounter rate = 2.4 crocodiles/km). The population sex ratio was 1:1, and the cutaneous parasite *Paratrichosoma* was found on 92% of the captured crocodiles. Our data suggest a relatively stable and healthy population of *C. acutus* on Caye Caulker, but recent increases in pollution and human settlement could threaten the viability of this population.

Key Words: Conservation management, crocodile demographics, mangroves, mark-recapture survey, nocturnal eyeshine survey, *Paratrichosoma* sp.

Resumen: Realizamos censos nocturnos y método de captura-recaptura para determinar el estado poblacional de *Crocodylus acutus* durante los meses de enero, marzo y abril de 2016 en Caye Caulker, Belice. Avistamos 55 cocodrilos en 22.15 km recorridos. La mayoría de cocodrilos ocupan el hábitat manglar costero en el sur (área más desarollada), y al norte (área menos desarollada) de la isla. La población de cocodrilos estuvo conformada por 36% jóvenes, 40% subadultos, 16% adultos y 7% se identificaron como solos ojos (2.4 cocodrilos/km respectivamente). La proporción de sexos fue 1:1, y el parásito *Paratrichosoma* se encontró en una incidencia del 92% de cocodrilos capturados. Nuestros datos resultados sugieren una población de *C. acutus* relativamente estable y sana en Caye Caulker, pero recientes aumentos en la contaminación y el crecimiento urbano podrían amenazar la viabilidad de esta población.

Palabras Claves: Censos nocturnos, demográficas del cocodrilos, manglares, marcaje captura-recaptura, *Paratrichosoma* sp., plan de manejo para la conservación

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INTRODUCTION

The American Crocodile (*Crocodylus acutus*) is a large-bodied crocodylian that primarily inhabits estuaries, coastal lagoons, islands, and atolls, as well as a few inland rivers and lakes throughout the Americas (Platt and Thorbjarnarson, 2000a; Thorbjarnarson et al., 2006). The range of this species extends from the southern tip of Florida, United States, to Venezuela along the Atlantic coast, and from Mexico to northern Ecuador along the Pacific coast, as well as islands on the Caribbean Sea (Platt and Thorbjarnarson, 2000a; Thorbjarnarson et al., 2006). The conservation status of *C. acutus* currently is regarded as Vulnerable by the IUCN, and this species is listed as Appendix I by CITES in the majority of its geographical range as a result of historical and present poaching, opportunistic killings, and habitat destruction (Platt and Thorbjarnarson, 2000a; Thorbjarnarson et al., 2006). Additionally, the IUCN/SSC-Crocodile Specialist Group recognizes this species as in critical need of conservation. In Belize *C. acutus* nearly was extirpated during the 1960s, because of overexploitation for skins and meat (Platt and Thorbjarnarson, 2000a; Thorbjarnarson et al., 2006). After *C. acutus* was afforded legal protection, offshore populations, especially in the Turneffe Atoll, have shown a slow recovery (Platt and Thorbjarnarson, 2000a; Rainwater, 2008). Similarly, *C. acutus* on Caye Caulker also might have recovered from past exploitation (T. Aguilar, pers. comm.; MB and MT, unpublished). Twenty years ago the population of *C. acutus* on Caye Caulker was still recovering from historical overhunting and continual deliberate killing (Platt, 1997). In recent years, however, accounts of *C. acutus* sightings and interactions (with minor conflicts) depict a larger population, and the local community has expressed a curiosity about the growing abundance of *C. acutus*. People also have voiced concerns about an increase in human-crocodile conflicts, especially because of the lack of adequate management plans. Although *C. acutus* sightings appear to have increased since the mid-1990s, data on the current population status is unavailable, as since 1997 no official survey has been conducted to assess the population size and demographics.

Successful accounts of crocodile populations recovering from the brink of extinction illustrate the significance of regular monitoring programs and ecological research (Kushlan and Mazzotti, 1989; Mazzotti et al., 2007; Thorbjarnarson et al., 2006). For example, populations of *C. acutus* in the United States, such as those at Turkey Point Power Plant and Crocodile Lake National Wildlife Refuge in Florida, were declared endangered in the late 1970s and early 1980s, but those populations have grown extensively as a result of a continuous and intensive research management program (Mazzotti et al., 2007). Similar research also has exposed a suite of anthropogenic factors (i.e., pollution, human settlement, poaching) that pose a threat to current or future conservation efforts for crocodiles and their habitats (Mazzotti et al., 2007; Platt and Thorbjarnarson, a, b; Venegas-Anaya et al., 2015). Recognizing such threats can facilitate the implementation of an appropriate action plan, in addition to lessening the number of human-crocodile conflicts (Caldicott et al., 2005). Thus, by gathering data on the population biology of crocodiles, in addition to surveying habitat health and fluctuations, a blueprint can be created for ensuring the long-term success of conservation monitoring programs for crocodiles and their habitats (Platt and Thorbjarnarson, 2000a; Venegas-Anaya et al., 2015).

Given the lack of data on the present status of *C. acutus* in Caye Caulker, along with the current patterns of human settlement and concerns voiced by the local community, a population survey is necessary for implementing an adequate conservation management plan to help mitigate human-crocodile conflicts. Thus, the principal goals of this study were to (1) obtain baseline population data for *C. acutus* on Caye Caulker via nocturnal eyeshine and capture surveys, and (2) to monitor human impact on the habitat of *C. acutus*. Based on our results, we provide recommendations for the conservation and management of *C. acutus* and its habitat, as well as to reduce perilous conflicts between the local community and the crocodiles.

MATERIAL AND METHODS

Study Area

From 24 to 26 March and 9 April 2016 we surveyed the population and distribution of *Crocodylus acutus* in Caye Caulker, Belize (17°45'9.83"N, 88°1'27.00"W; WGS 84; Fig. 1). Caye Caulker is located 1 mile (= 1.6 km) west of the Barrier Reef in northern Belize. A channel separates the less developed northern portion of the island, which is characterized by mixed mangrove scrub along the coast (*Rhizophora mangle*, *Avicenncia germinans*), deciduous broad-leaved lowland shrubland, herbaceous swamp, and tropical littoral forest, from the more developed southern portion, which consists of reduced mangroves and littoral forest. Historically, the dry season lasts from December to June, and the wet season from July to November. In recent years, however, the seasonal cycle has been altered, thereby affecting the length of the seasons. We conducted our study during the latter half of the historical dry season, but the previous year Caye Caulker only received brief periods of rainfall. No rain fell during the time of our study.

Fig. 1. (A) Average morphometric data of captured *Crocodylus acutus* separated in size class cohorts via colored circles: (a) juveniles (purple); (b) subadults (green); (c) adults (brown); and (d) eyeshine only (yellow). (B) Data collection method: (a) eyeshine survey (yellow); and (b) capture (green).

Survey Methods

We conducted our census for *C. acutus* via nocturnal eyeshine surveys (NES) and captures 30 min after sunset. We performed the NES and capture surveys one night (24 March) in a golf cart, to assess inland bodies of water, whereas the other three nights we used a 100 hp motorboat for surveying along the coast of Caye Caulker. We detected eyeshines by using a 200,000 candle power spotlight or LED headlamps. As suggested by Sánchez Herrera et al. (2011), we performed NES and capture surveys on separate nights, because (1) the route of the NES should remain at a constant velocity, and (2) the NES should be performed in the greatest silence (i.e., capture of *C. acutus* can be noisy and adversely effect the NES). We recorded our survey routes and GPS location points where *C. acutus* were sighted or captured with a Garmin eTrex 30x.

Nocturnal Eyeshine Surveys

We conducted the NES on the nights of 24 and 26 March and 9 April. Throughout the survey, we recorded the average beginning and ending air temperature as 28.4°C and 27.8°C respectively, and the average beginning and ending water temperature as 26.8°C and 29.1°C. Upon sighting a crocodile, we recorded the GPS coordinates, time, and distance of sighting (m). We also classified crocodiles by total length (TL) as hatchlings (TL < 30 cm), juveniles (TL = 31–90 cm), subadults (TL = 91–180 cm), or adults (TL > 181 cm) (Platt and Thorbjarnarson, 2000a). We classified individuals for which the TL could not be determined as "eyeshine only" (EO). We calculated the encounter rates as described in Platt and Thorbjarnarson (2000a).

Capture Surveys

We captured *C. acutus* on the nights of 24 and 25 March, and one capture occurred at the end of the NES on 9 April. The average air and water temperatures during captures were 28°C and 26.9°C, respectively. We began our captures on 24 March after completing the NES. We captured *C. acutus* by hand or with catchpole snares, and restrained individuals to obtain the following morphometric data: head length; snout length; cranial width; maxillary width; premaxillary width; preorbital hump length; preorbital hump width; total length; snout–vent length; tail width; and sex. We also examined individuals for health and the presence of external parasites. After collecting the data, we marked the crocodiles with a unique numerical code following the methods of Jennings et al. (1991), for future identification, as well as for future genetic and eco-toxicity studies. Once the data were collected, we released the crocodiles at the site of capture.

Habitat Monitoring

We examined the habitat occupied by *C. acutus* during the day on 25 March, noting the vegetative association and assessing any current and future threats the crocodiles might face, as presented in Sánchez Herrera et al. (2011). Briefly, we described the following major components: (1) types of water on each survey route; (2) types of habitat; and (3) presence or absence of human settlement. Following our description of the habitat we assessed the predominant human activity in the area, the state of most of the natural vegetation recorded (on a scale from 1 to 10, 10 = good), and recorded examples of pollution in the water (i.e., trash, chemical drainage, etc.) (Sánchez Herrera et al., 2011).

RESULTS

During three nights of nocturnal eyeshine and capture surveys, we encountered a total of 43 *Crocodylus acutus* along a 22.15 km route (Tables 1, 2). We likely failed to count four or five resident adult crocodiles in an interior lagoon on the northern part of Caye Caulker, as we were unable to gain access to the private land. Additionally, five crocodiles were sighted and seven were captured during a crocodile parasite study held from 6 to 11 January 2016, prior to our survey. Given that these captured crocodiles were not recaptured or sighted during our NES in March and April, we considered their data beneficial for our population survey and included it in this study. Thus, of the 55 crocodiles observed during the NES, we classified 20 (36%) as juveniles, 22 (40%) as subadults, nine (16%) as adults, and four (7%) as EO (encounter rate = 2.4 crocodiles/km; Fig. 2). Thirteen of the 50 crocodiles included in this survey were captured, for which we recorded various morphometric data (Fig. 3). Interestingly, the sex ratio was 1:1 (4 males:

4 females). Upon physical examination (i.e., tail and neck girth, etc.), the *C. acutus* appeared healthy; however, we found 92% of the captured crocodiles infected with the external parasite *Paratrichosoma* sp. (Fig. 4).

Table 1. Data on nocturnal eyeshine surveys on *Crocodylus acutus* conducted in Caye Caulker on 24 and 26 March and 9 April 2016.

Date	Starting Location	End Location	Distance Surveyed	Crocodiles Encountered	Encounter Rate
24 March	17°44'25"N, -88°01'65"W,	17°44'20"N, -88°01'92"W	3.8 km	12	3.2
26 March	17°44'41"N, -88°01'45"W,	17°44'40"N, -88°01'81"W	3.6 km	9	2.5
9 April	17°45'06"N, -88°01'49"W	17°44'42"N, -88°01'44"W	14.75 km	13	0.88
Totals			**22.15 km**	**34**	**1.5 crocodiles/km**

Table 2. Data for *Crocodylus acutus* captured in January, March, and April of 2016. Crocodiles for which sex could not be determined are marked as NA.

Date	GPS Coordinates	Total Length	Sex	Paratrichosoma Infection	Scute ID
8 Jan	17°47'10"N, -88°1'33"W	186.6 cm	Male	Yes	#807
9 Jan	17°44'42"N, -88°1'34"W	218.5 cm	Male	Yes	#808
10 Jan	17°44'12"N, -88°2'2"W	162.1 cm	Male	Yes	#809
11 Jan	17°34'30"N, -88°2'23"W	192.0 cm	Female	Yes	#810
24 March	17°34'30"N, -88°01'85"W	76.5 cm	NA	Yes	#814
25 March	17°45'86"N, -88°01'85"W	111.5 cm	Female	Yes	#815
25 March	17°45'86"N, -88°01'85"W	75.1 cm	NA	Yes	#816
25 March	17°46'52"N, -88°01'77"W	97.3 cm	NA	Yes	#817
25 March	17°46'98"N, -88°01'56"W	92.3 cm	NA	Yes	#818
25 March	17°47'05"N, -88°01'55"W	120.9 cm	Male	Yes	#819
25 March	17°47'76"N, -88°01'15"W	249.0 cm	Female	Yes	#820
26 March	17°43'30"N, -88°02'23"W	114.5 cm	Female	Yes	#821
9 April	17°47'60"N, -88°01'28"W	76.0 cm	NA	No	#823

Predominant bodies of water that characterize Caye Caulker include coastal waters (considered "other" in the habitat survey), a coastal lagoon, an estuary, and man-made canals. The principal human activities occurring within crocodilian habitat were human settlement, tourism, and fishing. The predominant vegetation on the caye was *Rhizophora mangle* (45%), followed by modified habitat (35%), and littoral forest (20%). The state of the natural vegetation of most of the habitat recorded was estimated as a 7, because the majority of the mangroves appeared healthy, pristine, and harbored various forms of wildlife. Trash and minor chemical drainage, however, was ubiquitous around human settlements.

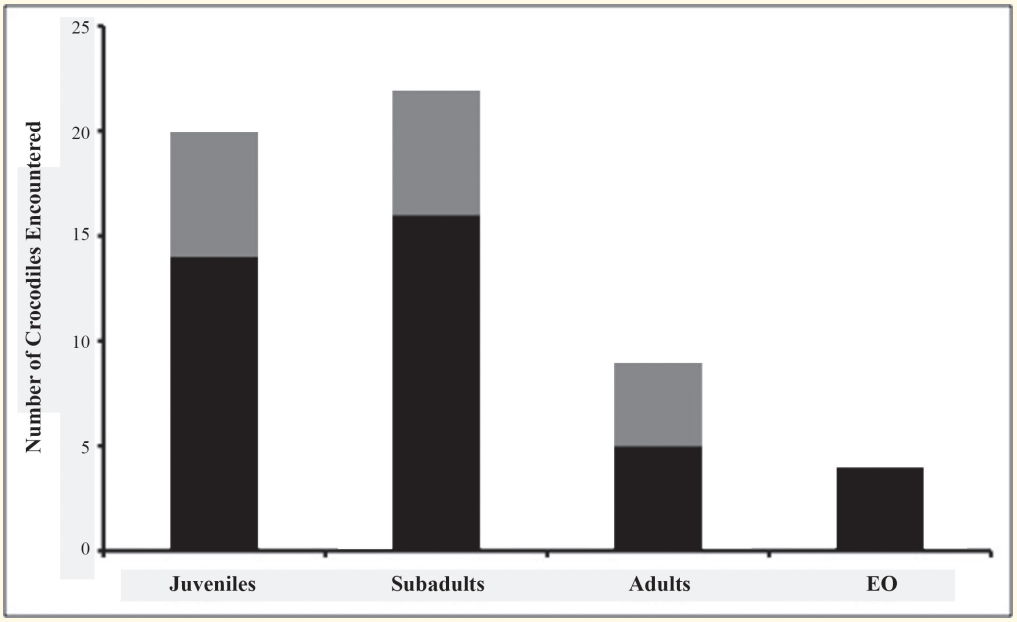

Fig. 2. Size class distribution of *Crocodylus acutus* encountered in January, March, and April of 2016. Gray area of the bar indicates crocodiles captured in that size cohort.

DISCUSSION

Our results confirm a relatively stable but possibly still recovering population of *Crocodylus acutus*, on account of the slight scarcity of adults and a bias toward smaller individuals. Although we found a 1:1 sex ratio, the capture of additional larger animals could provide important information to further validate the sex ratio of crocodiles on Caye Caulker, and might reinforce management plans. Additionally, the raw data do not illustrate significant patterns of preferred habitat occupied by the different size cohorts. Ontogenetic diet shifts, territorial aggression, and predation on smaller animals generally predispose crocodilians in various life stages to utilize different habitats (Chabreck, 1965; Joanen and McNease, 1970, 1972; Delany and Abercrombie, 1986). Future ontogenetic niche studies would be beneficial, as they might reveal cryptic habitat preferences among the various size cohorts, which could further conservation efforts by preserving specific habitats for crocodiles.

Paratrichosoma sp. is a nematode that infects the epidermal skin on the venter crocodiles, which is identified by cutaneous zigzagging trails (Ashford and Muller, 1978; Tellez and Paquet-Durand, 2011). The parasite is benign, and infected individuals are known to recover (MT, MB, KK, unpublished). Although a ubiquitous and familiar parasite among international field researchers and crocodile farmers, little data on the life cycle and environmental relationships between *Paratrichosoma* sp. and crocodylians are available. We found a 92% prevalence of *Paratrichosoma* sp. infection in the *C. acutus* on Caye Caulker, and all the crocodiles we observed appeared healthy given their robust neck and tail girth (Huchzermeyer, 2003). Interestingly, *Paratrichosoma* sp. is more

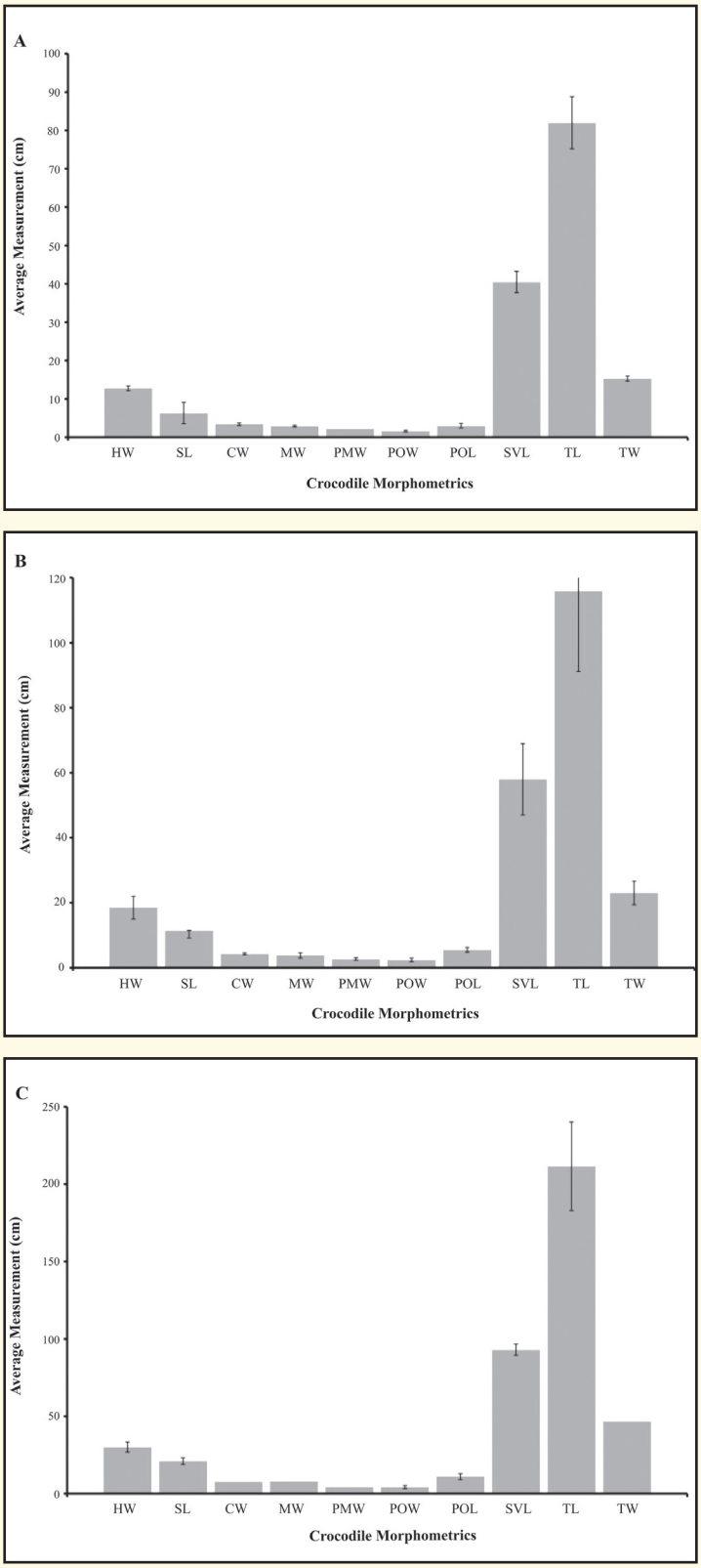

Fig. 3. Mean average morphometric data of captured *Crocodylus acutus* separated in size class cohorts: (A) juveniles; (B) subadults; and (C) adults. No yearlings were captured, thus no morphometric data is available. Abbreviations are as follows: head width = HW; snout length = SL; cranial width = CW; maxillary width = MW; premaxillary width = PMW; preorbital width = POW; preorbital length = POL; snout–vent length = SVL; TL = tail length; and TW = tail width.

prevalent on Caye Caulker than on Ambergris Caye (an island ca. 9 km N of Caye Caulker) (MT, unpublished). Previous and ongoing studies demonstrate a positive correlation between the prevalence of *Paratrichosoma* sp. to the pristine state or health and stability of the environment (Webb et al., 1983; Moravec and Vargas-Vázquez, 1998; MT, unpublished). *Paratrichosoma* sp. prevalence infected 100% of *C. moreletii* from Ría Celestún Biosphere Reserve, Yucatán, Mexico (Moravec and Vargas-Vázquez, 1998), and 100% of the juveniles, subadults, and adults of *C. johnstoni* from the McKinlay River, Northern Territory, Australia (Webb et al., 1983). Current research on *C. moreletti* from Chiquibul Forest, Belize, illustrates similar patterns as those in the aforementioned study on *C. johnstoni* (MT, unpublished). In the above studies crocodile populations were isolated from human development, and pollution was minimal. Thus, perhaps the current *Paratrichosoma* sp. data collected on Caye Caulker indicates a relatively stable and healthy environment, and future studies should assess the use of *Paratrichosoma* sp. as a possible biological indicator of the environmental state of crocodilian habitats.

The majority of *C. acutus* in the caye were found in coastal mangroves. Although the southern part of the caye is undergoing development, the remaining mangroves appear to contain acceptable habitat where animals can find food and shelter. The increasing amount of pollution in the mangroves along the southern part of the island, resulting from improper waste disposal, is of concern. Such pollution can cause a bioaccumulation of pollutants by crocodiles and other wildlife, mitigating any conservation efforts due to the adverse effects of heavy metal toxicity (Campbell, 2003; Zhou et al., 2008; Rabalais et al., 2009; Tellez and Merchant, 2015). Presently, the northern portion of Caye Caulker contains the most favorable habitat for *C. acutus*, because of the lesser amount of development, pollution, and human contact. The establishment of a forest and marine reserve in the northern part of Caye Caulker in the late 1990s likely has contributed to the preservation of crocodile habitat, and possibly to the current stable status of *C. acutus*. Additionally, the northern region, particularly around the forest reserve, favors successful nesting (T. Aguilar, pers. comm.), and provides an amalgamation of food for all size cohorts. Support and preservation of the forest and marine reserve should continue, as presumably its inauguration has contributed to the current healthy and stable status of *C. acutus* on Caye Caulker.

Twenty years ago the population of *C. acutus* on Caye Caulker was considered to be recovering from past exploitation, primarily because of the abundance of smaller crocodiles and the scarcity of adults observed (Platt, 1997). The Platt (1997) NES and capture survey recorded 52 crocodiles (48 encountered during the NES, four captured; encounter rate = 3.4 crocodiles/km). Although our encounter rate is lower than that in the previous study, it likely does not reflect a decline in the population size of *C. acutus* on Caye Caulker because (1) we surveyed a greater distance than in the previous study (particularly in the interior part of the island), and (2) we likely missed at least four or five larger crocodiles that are known to inhabit a lagoon on private land on the northern part of Caye Caulker. An additional factor is that we might have failed to count crocodiles along the northeastern side of the island, because the water level in this area was too low for the boat to pass through, so we surveyed far from the coastal mangrove. Consequently, we believe our crocodile encounter rate could have been similar or higher than that reported by Platt (1997). We also found more subadults and adults than previously encountered, which can be indicative of a stable reproductive population (P. Ross, pers. comm). Therefore, we suggest that the present crocodile population on Caye Caulker is relatively more stable than the population of 20 years ago.

The present *C. acutus* population on Caye Caulker might have benefited from increased wildlife enforcement that has mitigated illegal human-crocodile interaction. For example, 20 years ago the highest density of crocodiles was found in the island dump site, whereas our data illustrate a higher congregation of crocodiles within mangroves along the coast. Furthermore, our study crocodiles (with the exception of a few adults) were relatively easy to capture or approach to estimate their size, contrary to what was reported by Platt (1997). Previously, however, crocodiles apparently congregated at the dump site because it provided a safe-haven from human harassment and poaching, as it was difficult to identify or see crocodiles there due to various hiding outlets (Platt, 1997). Constant harassment or poaching activities also might have caused crocodiles to be weary of humans or boats, and thus they would have retreated at the sight or sound of human activity. During our study we found crocodiles of all size cohorts near or along the mangroves, with only a few reacting to our presence. Given the aforementioned data, we suggest that the population of *C. acutus* on Caye Caulker apparently is facing fewer threats of harassment and poaching, based on their current behavior. Increased awareness of wildlife laws and education during the last 20 years might have helped to alleviate fears and illegal actions toward crocodiles among the local community. Education and community outreach, such as school and community presentations, educational pamphlets, and social media outlets

should continue, as the current status of *C. acutus* suggests that years of public awareness perhaps contributed to the recovery of the local crocodile population and minimized human-crocodile conflicts on the caye.

In summary, our results indicate a relatively stable population of *C. acutus* on Caye Caulker, compared to the population 20 years ago (Platt, 1997); however, rapid and mismanaged development and pollution pose significant threats to the stability and health of the local crocodiles. To counteract such threats, continual community and financial support by FAMRACC (stewards of the forest and marine reserve), as well as local waste-disposal campaigns, are essential to ensure the preservation of *C. acutus* and other wildlife. We also suggest implementing a study to monitor the crocodile population on a monthly basis, to examine fluctuations in demographic patterns during the dry and wet seasons in conjunction with assessing habitat preferences among the size cohorts. Such information could assist in furthering the conservation management of *C. acutus*, as well as in alleviating human-crocodile conflicts. Finally, nest surveys are warranted, as they help estimate the abundance of the population, particularly of reproducing females.

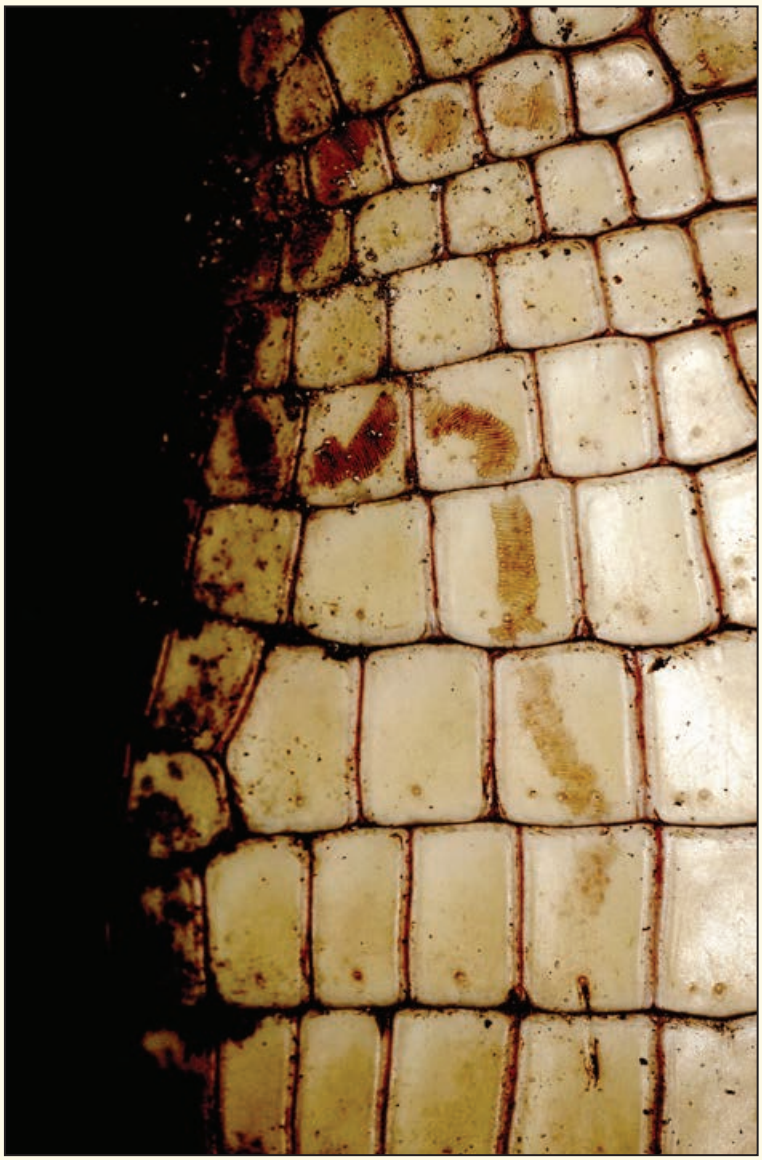

Fig. 4. Zigzag cutaneous trails of *Paratrichosoma* sp. found on a *Crocodylus acutus* in Caye Caulker, Belize.

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