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Assessment of American Crocodile, *Crocodylus acutus* (Crocodylidae), and Brown Caiman, *Caiman crocodilus fuscus* (Alligatoridae), Populations in the Paramillo National Natural Park, Colombia

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***Abstract.*—We assessed abundance and population structure of the American Crocodile (*Crocodylus acutus*) and Brown Caiman (*Caiman crocodilus fuscus*) from the Manso and Tigre rivers in Paramillo National Natural Park (NNP), Department of Córdoba, Colombia. This is a protected area in the remote northwest of the country, and is a potentially important area for the conservation of crocodilians. We surveyed 27.9 km of the Manso and Tigre rivers during February 2015. We observed 64 crocodilians, of which we reliably identified 49 (77%) individuals to species, with 37 identified as *C. acutus* and 12 identified as *C. c. fuscus*. Average encounter rate was 5.7 individuals/km for *C. acutus* and 2.8 individuals/km for *C. c. fuscus*. The total estimated population for the entire area surveyed of the Manso and Tigre rivers was 87 *C. acutus* and 35 *C. c. fuscus*. We found no significant difference in population structure (adults versus juveniles) between the species. We did find a significant difference in abundance and habitat preference between the two species, with *C. acutus* associated with flooded forest and *C. c. fuscus* associated with riverside forest. Our study highlights the importance of the Paramillo NNP for both national and regional crocodilian conservation planning.**

Evaluación de Poblaciones de Caimán Aguja, *Crocodylus acutus* (Crocodylia: Crocodylidae), y Babilla, *Caiman crocodilus fuscus* (Crocodylia: Alligatoridae), en el Parque Nacional Natural Paramillo, Colombia

***Resumen*.—Evaluamos la abundancia y la estructura de las poblaciones del Caimán Aguja (*Crocodylus acutus*) y la Babilla (*Caiman crocodilus fuscus*) en los ríos Manso y Tigre del Parque Nacional Natural Paramillo, departamento de Córdoba en Colombia. Estos ríos están ubicados en un área protegida remota, ubicada al noroeste de Colombia, y representa un área importante para la conservación de poblaciones silvestres de crocodílidos. Durante la temporada seca de la región, realizamos censos nocturnos que abarcaron 27.9 kilómetros de los ríos Manso y Tigre. De las 64 observaciones, logramos la identificación específica de 49 (77%), de las cuales 37 fueron identificadas como *C. acutus* y 12 como *C. c. fuscus*. La tasa de encuentro promedio fue de 5,7 individuos/km para caimanes y de 2,8 individuos/km para babillas. El tamaño total estimado de población para el área estudiada fue de 87 caimanes y 35 a babillas. No detectamos diferencias significativas en la estructura de la población (adultos vs. juveniles) para ninguna de las especies. Hallamos diferencias significativas entre la abundancia y el tipo de hábitat, *C. acutus* se asoció a bosque inundable y *C. c. fuscus* a rastrojos. Nuestro estudio resalta la importancia del PNN Paramillo para la conservación de crocodilianos a nivel nacional y regional.**

Key Words.—conservation; crocodilians; encounter rate; habitat preferences; Paramillo NNP

Introduction

Crocodilians are important and widespread inhabitants of tropical and subtropical aquatic habitats. Nearly all crocodilian species have been negatively affected by human activity (Grigg and Kirshner 2015). Overexploitation and loss or alteration of habitat have significantly impacted crocodilian species, affecting population dynamics and reducing population numbers (Thorbjarnarson 1992; Ross 1998; Morales-Betancourt et al. 2013). Interest in protecting and conserving crocodilian species has led to the development of numerous management and conservation efforts designed to improve the status of crocodilian populations in the wild (Thorbjarnarson 1992; Ross 1998). Such efforts require the identification of viable populations throughout the species range, as well as specific information on abundance, population structure, and population status, if management and conservation plans are to be effective.

Of the 10 crocodilian species inhabiting South America, six are found in Colombia, where they inhabit coastal and estuarine habitats, including rivers, lagoons, wetlands, and mangrove swamps (Morales-Betancourt et al. 2013). Two species inhabit the Caribbean coastal region of Colombia: the American Crocodile (*Crocodylus acutus*) and the Brown Caiman (*Caiman crocodilus fuscus*). At present, *C. acutus* is listed as Vulnerable by the IUCN and included in Appendix I of CITES (except for the population of Cuba, which is included in Appendix II), while *Caiman crocodilus* is listed as Lower Risk/least concern with *C. c. fuscus* included in Appendix II of CITES. Hunting, direct persecution, and loss or alteration of habitat have all significantly impacted populations of these species in Colombia (Morales-Betancourt et al. 2013). National and international trade restrictions, as well as the availability of legal skins from crocodile farms, have significantly reduced hunting in recent decades. However, populations of both species remain threatened (especially *C. acutus*), with a more complete understanding of population status and abundance essential to ongoing management and conservation efforts (De La Ossa et al. 2013; Morales-Betancourt et al. 2015). Despite increased conservation efforts over the years, large areas of potentially important habitat for crocodilian conservation in Colombia have not been surveyed, which impedes conservation national planning (Morales-Betancourt et al. 2013). This is due in part to the presence of outlawed armed groups in many remote areas of the country where studies would need to be conducted. One such area that has received little attention is the Paramillo National Natural Park (NNP; in Spanish, Parque Nacional Natural Paramillo). Paramillo NNP is a protected area in the remote northwest of Colombia, and is a potentially important area for crocodilian conservation, particularly for the threatened *C. acutus*. However, information regarding the status of crocodilian populations in this area is scarce, due to its remoteness, location, and the aforementioned presence of armed groups, which make access difficult and fieldwork a perilous undertaking.

Our study represents the first survey of *C. acutus* and *C. c. fuscus* populations in the Paramillo NNP, as well as the first study to assess the status of these species in riverine habitats in the Caribbean region in Colombia. Knowledge of population status will provide much needed information essential to the ongoing development of effective local and regional conservation planning for these species. Our primary objective in this study was to determine population size and status of *C. acutus*, as well as the less threatened *C. c. fuscus*, in Paramillo NNP. Additionally, we examined habitat preferences for each species.

Materials and Methods

Study area.—Paramillo NNP is a protected area located at the northern tip of the western branch of the Andes mountain range in northwestern Colombia, in the departments of Antioquia and Córdoba. The park covers approximately 460,000 ha, and protects the main extension of tropical rainforests and Páramos in the north of the country. Predominant vegetation in the study area is Tropical Moist Forest, referred to as Bh-T for its abbreviation in Spanish (Bosque húmedo - Tropical), with an annual temperature range of 26–30° C (Racero-Casarrubia et al. 2008). Rainfall in the study area is highly seasonal, with a dry season lasting from December to March and a rainy season from May to October, with April and November transitional months (Jaramillo and Chaves 2000; Rangel-Ch and Carvajal 2012). Annual rainfall in the study area is about 3,620 mm, with rainfall in the dry season about 69 mm. The park contains the source of the Verde and Esmeralda rivers (tributaries of the Sinú River), and the Sucio River (a tributary of the San Jorge River). The present study was undertaken on the Tigre and Manso rivers of Paramillo NNP (Fig. 1), and limited to the Department of Córdoba.

Survey methods.—We performed surveys 16–25 February 2015, using standard nocturnal spotlight counts (Chabreck 1966) during new and waning moon phases. We conducted nocturnal spotlight surveys 1900–0300 from a wooden boat (8 m length) while rowing approximately 1.0–2.5 km/h, with the exception of the Upper-Manso survey route that we surveyed on foot (Table 1). Using a handheld Garmin GPSMAP 60CSx unit (model number 010–00422–00,

Figure 1. (A) The upper Manso River, (B) lower Manso River, and (C) Tigre River and surveying boats in Colombia. (Photographed by Thomas A. Viloria-Lagares).

Garmin International Inc., Olathe, Kansas, USA), we determined the coordinates of the beginning and end of each survey route, with the length of each survey route determined using the odometer function. The presence of armed groups restricted movements in the study area, affecting the number of repetitions along some routes. We surveyed each route one to four times (Table 1).

We first located crocodiles by eyeshine using LED flashlights with 150 lumens. We then approached as close as possible to visually determine species and estimate size (total length) of the individual. We used readily distinguishable differences in gross morphology of the head and the presence a clearly visible bony ridge (or interocular ridge) between the eyes in *C. c. fuscus* (but not in *C. acutus*) to distinguish species. We visually estimated Total Length (TL) on the basis of head size and assigned individuals to one of two size classes: adults (reproductive individuals) and juveniles (non-reproductive individuals). We considered an individual adult if it had an estimated TL > 120 cm for *C. c. fuscus* (Ayarzagüena 1983) or > 180 cm for *C. acutus* (De La Ossa-Lacayo et al. 2013). We recorded individuals that submerged before species identification could be made as Eyes Only (EO). To evaluate possible associations between habitat preference and species, we recorded the habitat type where we found individuals. We classified habitat into three types: (1) flooded forest: mature forest or arboreal vegetation in different successional stages that remains flooded during periods of high water; (2) riverside forest: mature forest or arboreal vegetation in different successional stages, and cultivated areas that never flood during periods of high water; and (3) pastures: this included pastures for cattle intermixed with cultivated areas that flood during periods of high water.

Data analyses.—We estimated Encounter Rate (ER) for each species by dividing the number of observed individuals (excluding EO) by length of the survey route in kilometers. We obtained estimates of Population Size (EP) for each species by multiplying the number of recorded individuals per species by a Correction Factor (CF), where CF is 100 divided by the Visible Fraction (VF; Juan Sánchez, unpubl. report). We calculated VF as follows: (average number of identified individuals) / ((2*standard deviation) + (average number of identified individuals*1.05))100. This method corrects for the unknown proportion of individuals present in the study area but not observed (non-visible fraction), and is a commonly used method in crocodilian studies (Messel 1981; King et al. 1990). We calculated EP only for survey routes with replications, with EP calculated for the identified fraction (the fraction for which species identification was achieved) and EO fraction separately. For survey routes without replications, we used the number of observed individuals along a survey route to represent the EP estimate. Additionally, we calculated an estimate of Total Population Size (TP) for each species as follows: EP species + (EP of individuals identified as EO*relative abundance of each species), where the relative abundance of each species was obtained from the proportion of each species in the identified fraction.

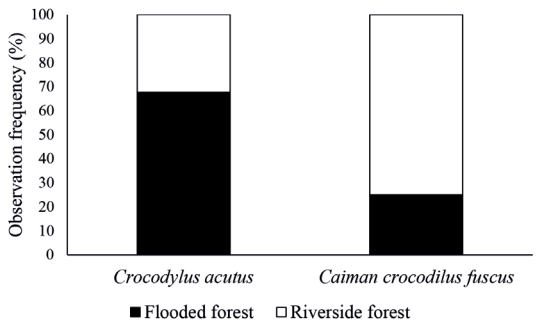

Figure 2. Frequency of occurrence of the American Crocodile (*Crocodylus acutus*; n = 37) and the Brown Caiman (*Caiman crocodilus fuscus*; n = 12) in riverside habitat types on the Rivers Manso and Tigre. No crocodilians were observed in pasture habitat.

We assessed differences in population structure (adults versus juveniles) between species using a Kolmogorov-Smirnov test ($\alpha = 0.05$; Massey 1951). We tested associations between the location of each species and habitat type using an Fisher's Exact Test of non-association (Fisher 1922).

Results

We surveyed 27.9 km of the Manso and Tigre rivers of the Paramillo NNP, limited to the department of Córdoba. Of the 64 crocodiles we observed, we identified 49 (77%) to species. We identified 37 individuals as *C. acutus* and 12 as *C. c. fuscus* (Table 2). We recorded the remaining 15 (23%) observations as EO (Table 2). The relative abundances of *C. acutus* and *C. c. fuscus* in the identified fraction were 0.76 and 0.24, respectively.

Average ER for *C. acutus* was 5.7 individuals/km, with the highest ER observed in the Upper-Manso route. Average ER for *C. c. fuscus* was lower (2.8 individuals/km), with the highest ER also observed in the Upper-Manso route (Table 2). With the exception of the Manso-Zancón route, for which we found no *C. acutus*, encounter rates for *C. acutus* were higher than those for *C. c. fuscus*. Based on the identified fraction, we estimated EP across all survey routes for *C. acutus* and *C. c. fuscus* to be 63 and 28, respectively (Table 2). The equivalent value of EP for EO was 31 (Table 2), corresponding to 24 individuals of *C. acutus* and seven individuals of *C. c. fuscus*, based on the relative abundance of each species observed in the identified fraction. Estimated TP for the entire area surveyed (total TP; Table 2) of the Manso and Tigre rivers was 87 for *C. acutus* and 35 for *C. c. fuscus*.

Of the 37 observations we made of *C. acutus*, all but one were juveniles, while for *C. c. fuscus* we observed nine juveniles and three adults. We did not find hatchlings of either species. We found no significant difference ($D = 0.500$, $P = 0.844$) in population structure (adults versus juveniles) between species. In contrast, we did find a clear difference in habitat preference between *C. acutus* and *C. c. fuscus* (Fig. 2), with *C. acutus* strongly associated with flooded forest (Fisher's Exact Test; $P = 0.017$) and *C. c. fuscus* strongly associated with riverside forest (Fisher's Exact Test; $P = 0.017$). Neither species was observed in riverside habitat with pastures.

Discussion

Although there have been a number of studies of this type in crocodilian species in Colombia, the majority have been conducted in more accessible areas of the country (Ulloa and Sierra 2006; Balaguera-Reina and Gonzalez-Maya 2008; Balaguera-Reina 2012; Espinosa et al. 2012; Castro-Herrera et al. 2013), with very few similar studies having been carried out in the more remote and inaccessible areas where information is lacking (however, see Ulloa 2011). One such area which has received very little attention to date is the Paramillo NNP, a remote and potentially important area for crocodilian conservation in northwestern Colombia. Our study represents the first assessment of population status of *C. acutus* and *C. c. fuscus* in the Paramillo NNP.

Encounter rate for *C. acutus* in our study is considerably higher (5.7 individuals/km) than those reported for most previous population surveys of *C. acutus* in Colombia: Cispatá Bay, 0.73 individuals/km

Table 1. Name, number of surveys made, length, and coordinates of the start point and end point for each survey route for the American Crocodile (*Crocodylus acutus*) and the Brown Caiman (*Caiman crocodilus fuscus*) on the Manso and Tigre rivers in Paramillo Natural National Park, Colombia.

Survey route	Surveys made	Length (km)	Start point	End point
Manso-Zancón	1	1.5	76°6'5.65"W 7°39'48.66"N	76°5'57.2"W 7°40'1.9"N
Lower-Manso	1	11.6	76°5'57.2"W 7°40'1.9"N	76°2'40.45"W 7°40'49.63"N
Upper-Manso	4	1.6	76°2'40.45"W 7°40'49.63"N	76°2'58.6"W 7°40'57.8"N
Tigre	2	4.2	76°2'40.45"W 7°40'49.63"N	76°1'44.43"W 7°40'31.52"N

in 2004 and 1.25 individuals/km in 2002 (Ulloa and Sierra 2006); Portete Bay in La Guajira, 1.2 individuals/km (Espinosa et al. 2012); and Zapatosa and Costilla swamps in Cesar, 0 individuals/km (Balaguera-Reina 2012). It is also considerably higher than encounter rates reported for surveys in continental riverine habitats in Colombia: Catatumbo region, Norte de Santander, 1.30 individuals/km (Ulloa 2011) and Ermitaño River, Santander-Boyaca, 1.07 individuals/km (Luis Fernando Barrera, unpubl. report). Interestingly, the ER observed in this study is similar to that reported for populations surveyed in other protected area in the country, such as Salamanca Island Road Park (7.78 individuals/km; Balaguera-Reina and González-Maya 2008), demonstrating the importance of such areas for crocodilian conservation planning. The similarity of ER from Paramillo NNP and Salamanca Island Road Park is of interest because it suggests populations of *C. acutus* can reach similar densities in both coastal mangroves (as in the case of Salamanca Island Road Park) and riverine habitats.

In regional terms, the ER for *C. acutus* on the Manso and Tigre rivers is also considerably higher than those previously reported for populations from Central America and the Caribbean (Table 3), with the only similar ER reported by Arteaga and Sanchez (1996) for populations surveyed in the Yaracuy River in Venezuela (2.52–7.13 individuals/km). Overall ER for *C. c. fuscus* was much lower (2.7 individuals/km) than for *C. acutus* (5.7 individuals/km). This result is most likely related to differences in habitat preference between the two species, with caimans preferring lentic ecosystems, where they are typically more abundant, than lotic ecosystems (Moreno-Arias et al. 2013). Encounter rate for C. c. fuscus in the Manso and Tigre rivers is higher than that previously reported for the Atrato River (0.6 individuals/km; Balaguera-Reina et al. 2010), but lower than that reported in habitats with high or intermediate levels of anthropogenic disturbance (e.g., Moreno-Arias et al. 2013, with 4.3 individuals/km). The low ER of *C. c. fuscus* in the Paramillo NNP is somewhat unexpected. However, because caimans are an important source of food for indigenous settlements close to the study area (Racero-Casarrubia et al. 2008), hunting of this species in the Paramillo NNP possibly contributes to this lower than expected ER.

The relationship between habitat type and the distribution of both species detected here is in agreement with previous assertions of microhabitat partitioning between crocodiles and caimans (see Seijas 1996; Espinosa-Blanco and Seijas 2010). It is probable that an important component of the habitat partitioning documented here is attributable to differences in habitat quality, with *C. acutus* more abundant in areas with more conserved habitat, and *C. c. fuscus* more abundant in less conserved habitat. For example, *C. acutus* was found to be more abundant in the Upper-Manso and Tigre River survey routes, areas of well-conserved forest habitat that is flooded (Martínez et al. 2005). In contrast, *C. acutus* was found to be scarce along the Lower-Manso and Manso-Zancón routes. These latter areas contain the highest levels of human activity in the study area (e.g., cattle grazing or legal and illegal agriculture; Martínez et al. 2005) and could be easily used by *C. c. fuscus*, which is regarded as a more generalist species (De La Ossa and De La Ossa-Lacayo 2013). The effects of habitat quality on the distribution of crocodilian species have been reported previously (Magnusson 1985; Mazzotti et al. 2009).

Our finding that almost all *C. acutus* encountered were juveniles (only one adult was detected) also was somewhat unexpected. Whether this reflects the underlying population structure is unclear; however, a similar finding was reported by Balaguera-Reina and González-Maya (2008). The low number of adults is consistent with the results of other studies (Balaguera-Reina and González-Maya 2008; Espinosa et al. 2012; Mauger et al. 2012), and may represent a non-ideal

Table 2. Number of observed individuals (Obs), estimated visible fraction (VF), estimated population size (EP) and encounter rate (ER) for the American Crocodile (*Crocodylus acutus*) and the Brown Caiman (*Caiman crocodilus fuscus*), as well as eyes only (EO) observations, recorded on the Manso and Tigre rivers, Colombia. Total population size (TP) is reported for *Crocodylus acutus* and *Caiman crocodilus fuscus* for the entire area surveyed along the Manso and Tigre rivers. See text for details.

	Crocodylus acutus				*Caiman crocodilus fuscus*				EO			
Survey route	Obs	VF	EP	ER	Obs	VF	EP	ER	Obs	VF	EP	ER
Manso-Zancón	0	-	0	0	2	-	2	1.3	1	-	1	0.7
Lower-Manso	10	-	10	0.9	5	-	5	0.4	2	-	2	0.2
Upper-Manso	15	37.9	24	15.2	3	18.2	11	7.1	11	31.2	23	14.4
Tigre	12	41.8	29	6.8	2	19.2	10	2.4	1	19.2	5	1.2
Obs (Total)		37				12				15		
EP (Total)		63				28				31		
TP		87				35				NA		

Table 3. Encounter rates reported for American Crocodile (*Crocodylus acutus*) in riverine habitats.

Location	Encounter rate (individuals/km)	Source
Belize	0.02	Platt and Thorbjarnarson (2000)
Costa Rica	2.90–4.50	Sanchez et al. (1996)
Honduras	0.51	Thorbjarnarson (1989)
Peru	0.18	Escobedo-Galván and Mejía-Vargas (2003)
Venezuela	2.52–7.13	Arteaga and Sanchez (1996)

scenario for a recovering population (Balaguera-Reina and González-Maya 2008). Alternatively, it is possible that larger individuals are inherently more wary and thus less likely to be observed (Messel 1981; Ouboter and Nanhoe 1988). This could be the case in the present study as we observed several adult crocodile footprints along the banks of both rivers (although no formal attempt was made to quantify these results), suggesting that adult individuals may have been underestimated in this study. Despite our study supporting the pattern of differential habitat use between *C. acutus* and *C. c. fuscus*, further survey efforts are clearly required on both the Tigre and Manso rivers if the causes underlying the observed population structuring are to be fully understood.

Conservation implications.—The identification and protection of viable crocodilian populations and their habitat in Colombia is crucial to continuing local and regional management and conservation planning. Thorbjarnarson et al. (2006) identified the most important areas for the conservation of *C. acutus* (referred to as Crocodile Conservation Units, CCU) across eight distinct bioregions. The location of the population of *C. acutus* in Paramillo NNP within the range of the species makes it important in terms of regional management because it represents one of the most important populations of the Caribbean South America bioregion. Furthermore, although we performed no formal statistical analysis, based on the criteria for defining CCUs described by Thorbjarnarson et al. (2006), we consider that the population of *C. acutus* in Paramillo NNP most likely represents an additional CCU within the Caribbean South America bioregion.

The ability of individual crocodiles to disperse long distances (Meredith et al. 2011; Rodriguez et al. 2011) illustrates the importance of protecting all potential crocodile habitat. It is unknown whether or not *C. acutus* populations in Colombia are linked by gene flow. However, a recent mDNA study (Thomas Viloria-Lagares and Paul Bloor, unpubl. data) revealed the presence of geographical restricted haplogroups within *C. acutus* in Colombia, suggesting that dispersal was historically restricted among populations. If dispersal and gene flow are shown to be restricted among *C. acutus* populations in Colombia, then the *C. acutus* population of Paramillo NNP may be of conservation importance because it could represent a geographically isolated source population for the Sinú and San Jorge basins. However, sampling of wild populations and analysis of rapidly evolving molecular markers, such as microsatellite DNA markers, will be required to establish whether this population is presently geographically isolated or not.

While our study highlights the importance of the Paramillo NNP for *C. acutus* conservation and management planning, there are several conservation concerns that have been detailed by Morales-Betancourt et al. (2013). For example, despite being within a protected area, information suggests that these populations are used by local communities (Racero-Casarrubia et al. 2008). While local use of crocodilians is not incompatible with management and conservation programs (Thorbjarnarson 1999; Velasco and De Sola 2005), continued research on this potentially important *C. acutus* population is necessary to determine the effects of local extraction on long-term population dynamics and viability. This is especially important as Colombia enters into the post-conflict era. Finally, despite the limited observations resulting from the difficulties associated with the presence of armed conflict in the area, our study provides estimates of population status that can serve as a baseline for continued management and conservation planning in Colombia.

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