Spatial ecology of the American crocodile and Spectacled caiman in Tayrona Natural National Park: A tool for conservation

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Abstract

Colombia is one of the most crocodylian diverse countries in the world. However, the spatial ecology of *Crocodylus acutus* and *Caiman crocodilus* in the wild is largely unknown. To date, no studies have been carried out in the country to understand the spatial dynamics of these species and their relationship with the environment through radiotelemetry. This pilot study evaluated the spatial ecology of these two sympatric species in the eastern sector of Tayrona National Natural Park (Arrecifes and Cañaveral localities), using VHF transmitters during the first half of 2021. A total of 275 records were obtained from six monitored individuals with age ranges of juvenile and adult for *C. acutus* and subadults for *C. crocodilus*. Specifically, two males and one female were monitored for each species with an error rate of 12.69% and frequency of monitoring per day of 1.02±0.56 and 0.61±0.37 respectively. The home range was determined with Minimum Convex Polygon (MCP), Local Convex hull (LoCoH), and Kernel Density (KD) with isopleths at 100%, 95%, and 50%, finding in those methods a maximum range for *C. acutus* of 0.189 km^2 and 0.042 km^2 for *C. crocodilus*, with LoCoH being the most accurate method. Only two individuals showed significant spatial autocorrelation (I-Moran z-score:2.65, p-value:0.08e-01 and z-score:2.23, p-value:0.26e-01) with confidence greater than 97% and an optimized hot spot analysis corresponding to a clustered distribution, which is probably associated with the amount of spatial data.This study also allowed us to identify areas of greater prevention of negative interactions between crocodylians and humans within the eastern sector of the TNNP. However, all individuals have an Average Movement Distance (AMD) <1km, in five months (Feb-Jul), with an extended dry season in the field from 2021. It was checked that *C. acutus* presented significantly greater displacements than *C. crocodilus* (p-value = 3.82e-06, p-value = 1.53e-05, respectively).Generalized linear regressions with negative binomial distribution tested the positive influence of mean precipitation (MP) with the onset of rainfall in July on the weekly AMD of *C. acutus* (MP z-value: 2.04, p-value:0.04, 95% confidence). In contrast, the weekly DMRs of *C. crocodilus* were affected by more environmental co-variables: solar radiation, PP, mean and minimum temperature (z-value: 2.12, p-value: 0.33e-01; z-value: -2.01, p-value: 0.45e-01; z value: -2.42, p-value:0.16e-01, respectively). The most robust model obtained for *C. crocodilus* has an explanatory power of 87.76%, compared to 31.41% for *C. acutus*. Therefore, it is necessary to increase the number of individuals and monitoring time, as well as to explore more abiotic and biotic variables that may be influencing the DMR of the study species. Finally, these spatial data provide valuable information for management plans and future research inside and outside the protected area for the conservation and management of crocodylians and the ecosystems associated with their distribution.

Introduction

Studying movement patterns and home ranges are important to understand the spatial conditions that individuals need to obtain food, grow, and reproduce (Millspaugh and Marzluff, 2001). In turn, it allows us to explain life history (Hutton 1989) and to know the Spatio-temporal scale variability of

behavioral and dispersal processes occurring within the distribution area (Kay 2004). For these reasons, assessing spatial ecology in crocodylians is vital for species management and protection (Fletcher and Fortin 2018) and it contributes to knowledge of impacts on lower trophic levels and habitat use in associated ecosystems (Rosenblatt et al. 2013). In this research, we select *Crocodylus acutus* (Cuvier, 1807) and *Caiman crocodilus* (Linnaeus, 1758), which are sympatrically distributed in Colombia, as study models. Currently, fragmentation, deforestation, and illegal hunting are limiting the areas of occupancy for the two species at the national level (Morales-Betancourt et al., 2013). Monitoring efforts are scarce in Colombia, where there is still a lack of knowledge of the presence-absence of populations in different areas of the country, making it difficult to make decisions for their conservation and sustainable use (Balaguera-Reina et al. 2015).

The study was conducted in the Tayrona National Natural Park (TNNP), which plays an important role as a Protected Area (PA) for populations of both species (Farfán-Ardila et al. 2019). An increase in *C. acutus* sightings has been reported in ecotourism areas, which may be sharing distribution areas with humans within the PNNT (Balaguera-Reina et al., 2012; Farfán-Ardila et al., 2019). Previous radiotelemetry studies on *C. acutus*, demonstrate low representativeness of what is occurring spatially for the species (Balaguera-Reina et al. 2016) because populations have only been investigated in Panamá (Rodda 1984; Balaguera-Reina et al. 2016), United States of America (Mazzotti 1983; Gaby et al. 1985; Kushlan and Mazzotti 1989; Cherkiss et al., 2014; Beauchamp et al., 2018) and Jamaica (Beauchamp et al. 2019) of the 18 countries its entire distribution (Rainwater et al., 2021). In the case of *C. crocodilus*, this is not an exception, as it has only been studied in Suriname (Ouboter and Nanhoe 1988), out of the 20 countries in which it is distributed (Balaguera-Reina & Velasco, 2019).

Therefore, it is necessary to understand the movement patterns and home ranges of these two species through radio telemetry, as well as prevent negative interactions in coexistence with visitors and locals within the PA (Balaguera-Reina et al., 2019). To know which are the areas of activity and movement patterns in the first semester of 2021, their relationship with environmental variables, and the distribution type of the crocodylians in a dry season.

Methods

Study Area. The study was carried out in Arrecifes and Cañaveral, in the eastern sector of the PNNT, located on the Colombian Caribbean coast. This PA covers an area of 15,000 ha, 12,000 ha terrestrial and 3,000 ha marine, and is characterized by its altitudinal gradient between 0-900 m asl, average environmental temperature of 27°C and relative humidity of 79% (Rueda-Solano et al. 2010), with marine-coastal ecosystems such as sandy beaches, rocky coastline, madreviejas, mangroves, and tropical rainforest.

Capture, tagging, and installation of transmitters. Based on reports of sightings in the eastern sector of the PNNT for the order Crocodylia (Balaguera-Reina et al., 2012; Farfán-Ardila et al., 2019;

Balaguera-Reina et al., 2020). Crocodylians were located by the ocular reflection of the *tapetum lucidum* (Chabreck, 1963). For capture and handling, the modified methodology of Sánchez-Marín (2014) was followed, and sexed and morphometric data were taken for each individual (Platt & Thorbjarnarson 2000; De La Ossa, 2002; Balaguera-Reina et al., 2010). Then, the tails of the individuals were marked through the cutting and removal of single scales (De La Ossa, 2001). To install the very high frequency (VHF) transmitters, we used the Telenax® brand (TELENAX, 2020), with the TXE-311BR (26g; 17x55mm), TXF-315BR (36g; 17x85mm) and TXF-317BR (70g; 17x55x31mm) transmitter models. Only individuals that exceeded LT > 1m were considered and also the weight of the transmitter must not exceed 5% of the specimen weight (Brander and Cochran, 1971). The transmitters were installed on the nuchal scales following the methodology of Brien and collaborators (2010). Once the installation was completed, the individuals were released to the same place where they were captured.

Monitoring and triangulation record. The research was performed for five months and five days, from February 15, 2021, to July 20, 2021. Seventeen monitoring routes were established in the eastern sector of the PNNT (Fig.1), to obtain the locations of each animal daily in three search days (morning, afternoon, and evening), the GPS position of each individual was recorded from at least three different stations, at a minimum distance of 10m between them (precision error ≤ 3m, Garmin® eTrex 10), with the respective azimuth in direction and sense to the frequency, heard between the range of 216.060 - 216.843MHz using the Tr-8 138-235MHz receiver of Telonics S. A® brand (Telonics, 2020). Then the monitoring that followed the filtering parameters proposed by Balaguera-Reina et al. (2016) were triangulated. The geolocations generated in ArcGIS Pro 2.8 (ESRI, 2021) were determined in "model builder" (ESRI, 2021). After this, outlier locations that had a very significant standard distance error (>100m) after triangulation were filtered out again (White and Garrott, 1990).

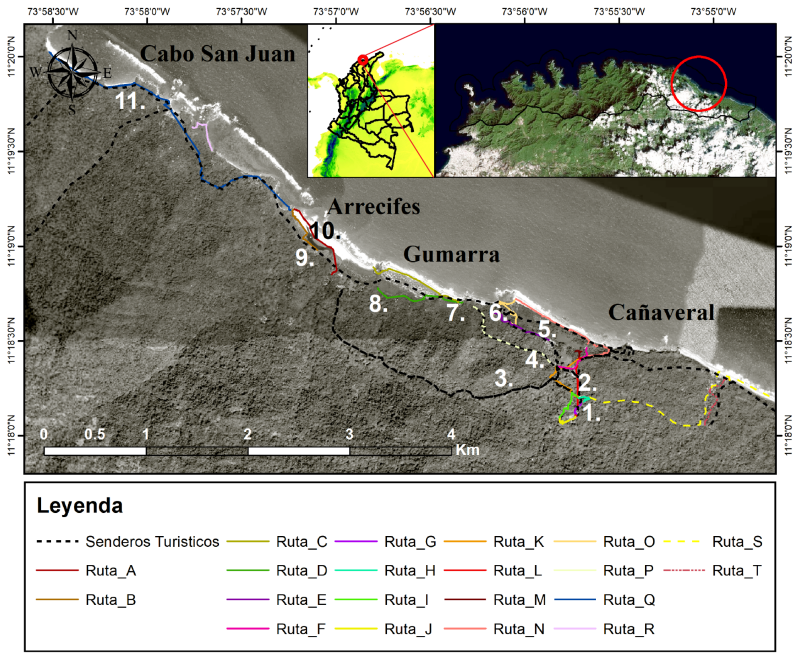


Fig 1. Monitoring and search routes for crocodylians during the dry season in the eastern sector of the Tayrona National Natural Park, Colombia in 2021-I. Being the tourist trails: 1-Administration, 2-Parking, 3- Horse stables, 4-Kogui, 5-Ecohabs, 6-La Piscinita, 7-San Felipe Bridge, 8-Los Almendros, 9-Arrecifes crossing with Quebrada San Lucas, 10-Arrecifes near to Madre Vieja and 11-Cabo San Juan.

Spatial analysis: autocorrelation, spatial patterns and home ranges. Average mean distance (AMD), Maximum movement distances (MMD) were determined using the ArcMET extension (Wall, 2014) for ArcMap 10.6 (ESRI, 2018). Moran's I test (Moran, 1950) was performed to determine the global autocorrelation between locations for each individual (Siabato and Guzman-Manrique, 2019; ESRI, 2022). Consequently, an optimized hotspot analysis was also executed for each individual by counting occurrences within a hexagonal grid by ArcGIS Pro 2.8 (ESRI, 2021). For home range estimation, the deterministic Minimum Convex Polygon (MCP) method (Mohr, 1947), Kernel Density (KD) (Worton, 1989), and adaptive local convex hulls (aLoCoH) (Getz et al., 2007) with 50%, 95%, and 100% isopleths were used by ArcMap 10.6 (ESRI, 2018). To compare the three methods for each species and highlight the minimum areas where they would spend 95% of their utilization distribution (UD), as well as their core area (50% UD), corresponding to the area where there is a potentially greater activity of individuals (Downs et al., 2011).

Statistical analysis. For each individual, we averaged the AMD weekly (AMD-W) and performed a Kruskal Wallis test (Kruskal and Wallis, 1952), and determined the homogeneity of variances using Levene's test (McDonald, 2014). Only data from "Joselito" (*C. acutus*), "Rosa" and "Hugo" (*C. crocodilus*) were used, because "La Juiciosa", "Pepe" and "Lulo" had a low number of AMD-W data recorded in the field. To understand the variation of the AMD-W of the species as a result of environmental co-variables, we used generalized linear models (GLM) with a negative binomial distribution (Nelder and Wedderburn, 1972), taking into consideration the AIC and pseudo - R2 McFadden. We evaluated three models in *C. acutus*, the first using the co-variables of average precipitation (AP) and relative humidity (RH), the second with solar radiation (SR), average temperature (AT), maximum (Tmax), minimum (Tmin) and the third with the sum of the co-variables of the first and second model. In the case of *C. crocodilus*, three models were also evaluated, the first using only the individual variable (IND), the second with the environmental co-variables AP, RH, SR, AT, Tmax, and Tmin, followed by the third model with the sum of all covariates. This climatic information was collected from the meteorological station of the Cañaveral sector (11.3027139 N, -73.9279724 W) provided by the PNNT. Finally, statistical analyses were performed in RStudio version 4.1.1 (Rstudio Team, 2020).

Interesting findings

In the field, nine American crocodiles were captured and four of them were recaptured during the six-month tracking period; Spectacled caimans were 17 captures and four recaptures, respectively, and only six individuals were suitable for the installation of transmitters (Table 1), for a total of 275 monitoring events with a total error rate of 12.69% (167 de *C. acutus* y 108 de *C. crocodilus*).

Table 1. Data of individuals tagged and tracked with VHF transmitters in the eastern sector of the Tayrona National Natural Park. *On April 13, transmitter No. 6 was dropped and on May 8 transmitter No. 7 was installed again; **For this frequency the 15 days of monitoring by the direct sighting of individual 77 were included.

Species	***C. acutus***	***C. acutus***	***C. acutus***	***C. crocodilus***	***C. crocodilus***	***C. crocodilus***
Name	**"Joselito"**	**"La Juiciosa"**	**"Pepe"**	**"Rosa"**	**"Lulo"**	**"Hugo"**
Age group (De La Ossa, 2002; Balaguera-Reina et al., 2010)	**Juvenil**	**Juvenil**	**Adult**	**Sub-adult**	**Sub-adult**	**Sub-adult**
	CLASE III	**CLASE III**	**CLASE V**	**CLASE III**	**CLASE III**	**CLASE III**
ID	**11**	**4**	**77**	**11**	***7***	***10***
# Transmitter	6-7*	10	16	2	12	8
Frequency (MHz)	216.269 216.060	216.390	216.691	216.089	216.843	216.329
Model	TXE-315BR	TXE-315BR	TXE-317BR	TXE-317BR	TXE-317BR	TXE-315BR
Transmission start	16/02/21	21/02/21	16/02/21	12/05/21	17/05/21	12/05/21
Transmission end	20/07/21	28/02/21	17/02/21	20/07/21	20/07/21	20/07/21
Transmission days	126	7	1	69	64	69
# Records (pre-filter)	176	9	6	69	17	38
#Records (post-filter)	153	8	6	61	15	32
Frequency of records per day	1.40	1.29	0.37**	1.00	0.26	0.55
(%) record error	13.06	11.11	0	11.59	11.76	13.51

- Average mean distances traveled were 0.24 km for *C. acutus* and 0.04 km for *C. crocodilus*. We found that American crocodiles moved more than the Spectacled caimans (MWW test p-value = 3.82e-06, p-value = 1.53e-05, respectively).
- We recorded that Joselito had a greater total distance traveled, it was the animal with greater records and monitoring time during the entire 2021-1 dry season. However, it did not move more than 0.8 km in the entire study area. Otherwise, in the short monitoring time for Pepe, it traveled 1.61 km from the madrevieja of Arrecifes to the San Felipe beach.
- It was found that MCP (100%) for *C. acutus* (35.56 ha) and *C. crocodilus* (5.12 ha) estimated a larger home range than aLoCoH (11.53 ha; 1.46 ha), followed by KD (0.62 ha; 0.26 ha), respectively. For both MCP and KDE, an overestimation of the area of the monitored individuals was evident; LoCoH shows the home ranges more accurately because it is adjusted to the habitat requirements and possible geographic barriers.
- In the case of Pepe, it was only possible to estimate the MCP and aLoCoH due to the low amount of events recorded, however, this adult with 6 locations was the one that obtained the most area of use for the species. Nevertheless, the individual that recorded the largest core area (50%UD) was Joselito in the three methods (MCP: 2 ha, KDE: 0.2 ha, and aLoCoH: 1 ha), which was located in the madreviejas of Arrecifes and La Gumarra beaches (Fig. 2).

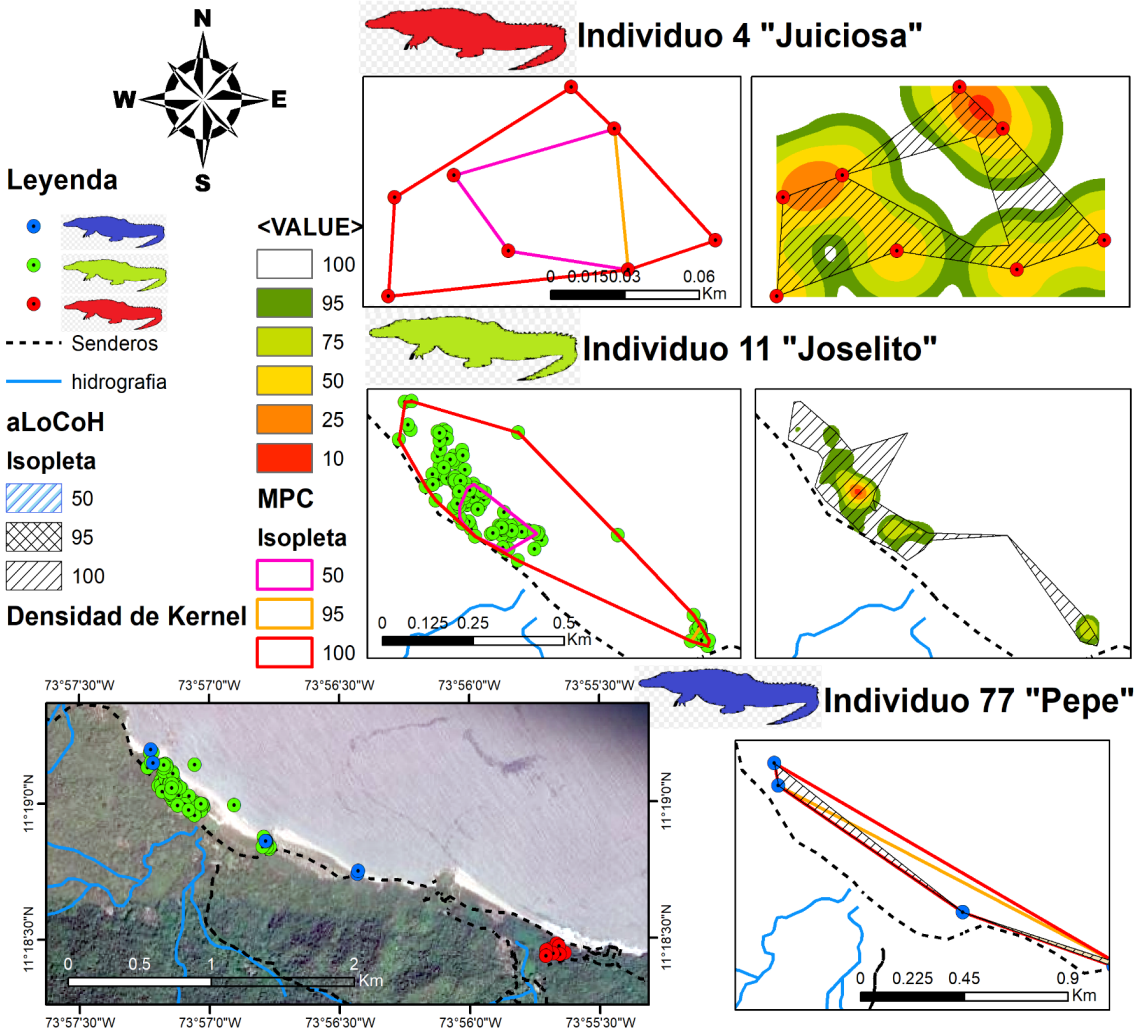


Fig 2. Home ranges of *Crocodylus acutus* using the minimum convex polygon method (MPC), kernel density (KD), and adaptive convex hulls (aLoCoH) during the dry season in the eastern sector of the Tayrona National Natural Park, Colombia (2021-I).

- In contrast to the Spectacled caimans' home ranges, they occupied smaller areas with a restricted distribution in the tropical rainforest of the Cañaveral sector (Fig. 3), away from the beach. It was observed that the movements of *C. crocodilus* were less than one kilometer, as well as their average velocities traveled.
- It was found that there is a significant difference between the AMD-W of Hugo and Rosa (MWW test p-value = 0.03; p-value = 9.77e-04, respectively), which suggests that there may be an intraspecific variability between the individuals, being greater the AMD-W of Hugo than Rosa.

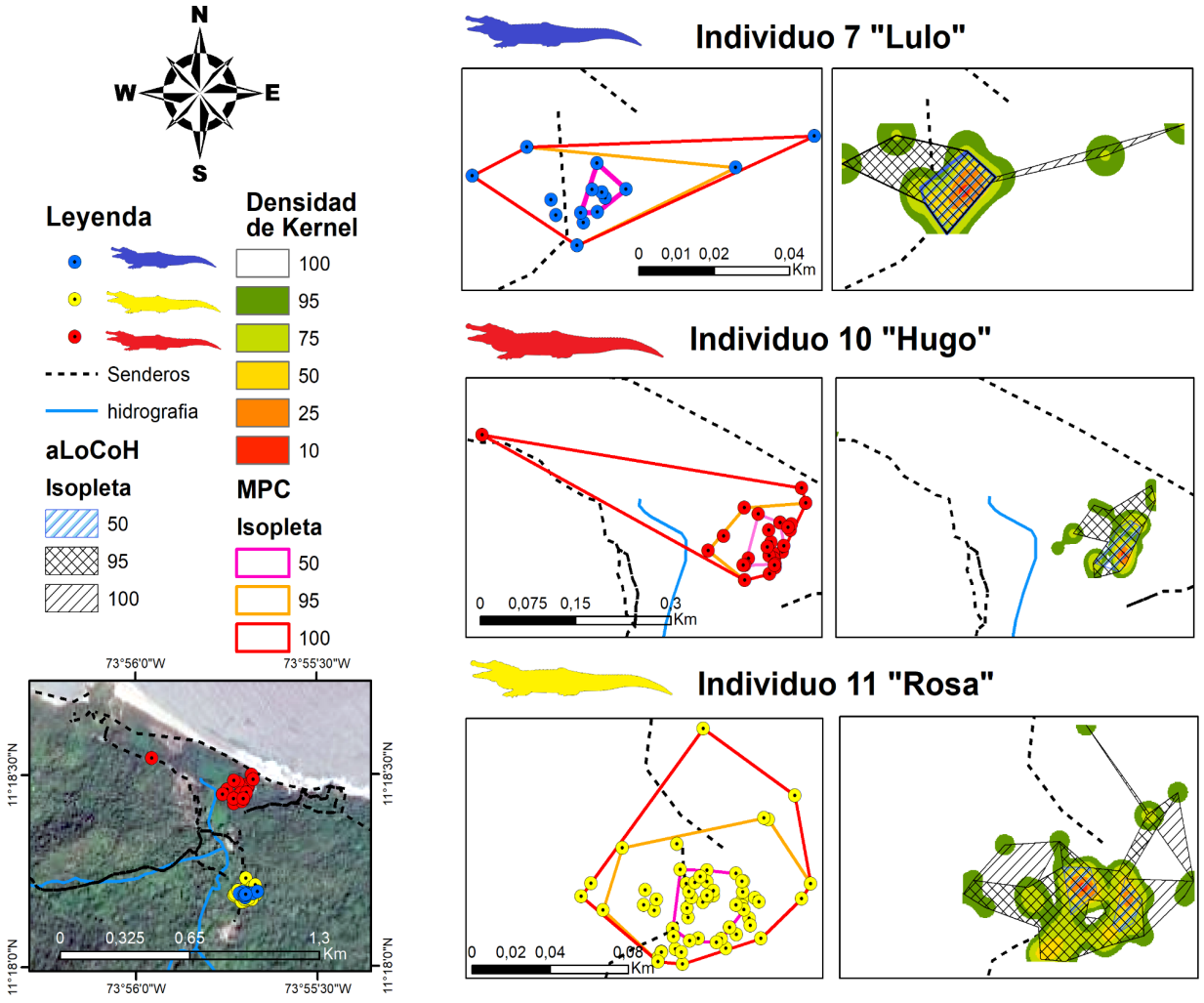


Fig 3. Home ranges of *Caiman crocodilus* using the minimum convex polygon method (MPC), kernel density (KD), and adaptive convex hulls (aLoCoH), during the dry season in the eastern sector of the Tayrona National Natural Park, Colombia (2021-I).

- Studying the spatial explicit behavior of the locations for each individual, it was found that these locations for Joselito, La Juiciosa, Pepe, and Lulo did not have a significant spatial autocorrelation (I-Moran z-score: 6.62 p-value: 0.00; z-score: -0.04 p-value: 0.96; z-score: 1.69 p-value: 0.09; z-score: 0.095 p-value: 0.92 respectively). In the opposite case occurred with Rosa and Hugo (I-Moran z-score: 2.65 p-value: 0.08e-01 and z-score: 2.23 p-value: 0.26e-01), their values showed that the locations of the two individuals are aggregated with 99% and 97% confidence, respectively, corresponding to a clustered distribution (Fig 4.).

- We found that the management of Joselito did affect its spatial distribution. We prove that the recapture of this juvenile in May drastically changed the significance of Joselito's spatial autocorrelation for the optimized hotspot analysis. We denoted a difference with 100% of the Joselito locations (z-score: 6.62 p-value: 0.00) and 87.59% of the Joselito locations without the La Gumarra data (z-score: 3.57 p-value: 0.04e-02).

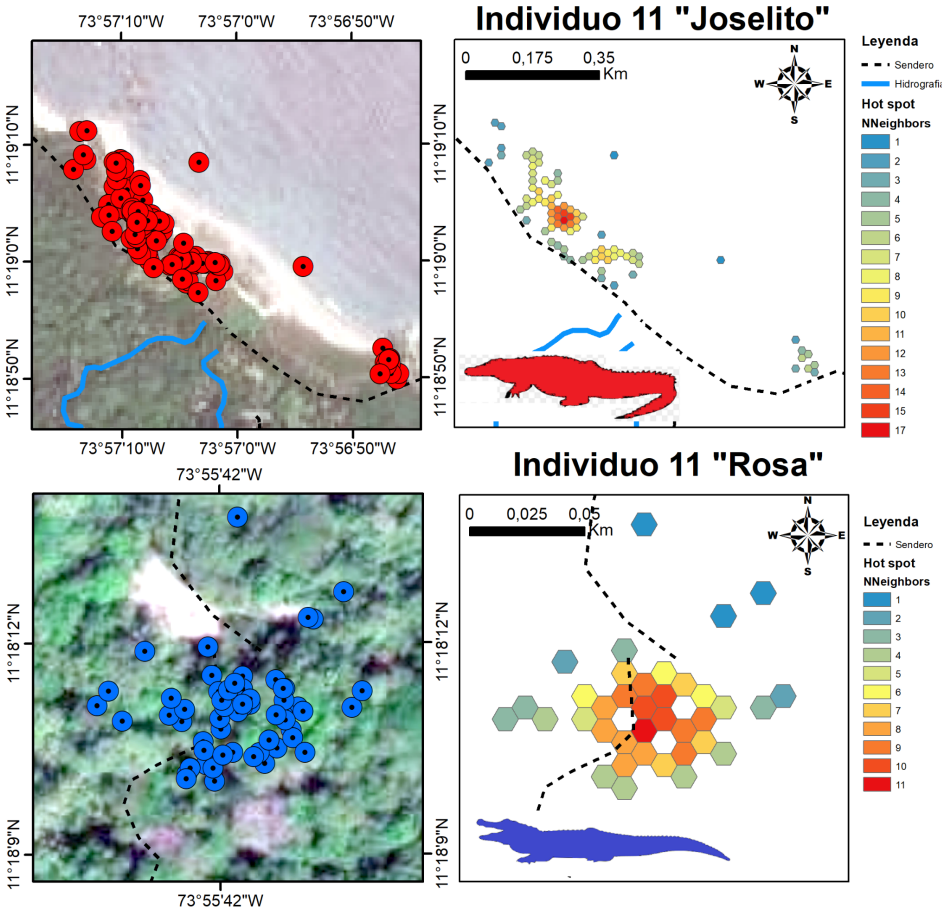


Fig 4. Optimized hotspot analysis for *Crocodylus acutus* ("Joselito") in the Arrecifes locality and *Caiman crocodilus* ("Rosa") in Cañaveral during the dry season in the first semester of 2021. Geolocations of monitored individuals (left) and analysis of hot spots (right).

- We also highlight that the clusters of the two species overlap with the tourist trails, for Spectacled caimans in Cañaveral (Horse stables, Ecohabs, parking, and administrative area), which in the case of American crocodiles only crossed in the locality of Arrecifes (madrevieja and sandy beach) (Fig 4). The analysis of optimized hot spots helped to identify areas where it is necessary to increase the signaling of crocodylians' presence, specifically in the tourist trails: 1, 4, 5, 6, 7, 9, 10, and 11 (Fig. 1).

- We found the significant influence of average precipitation (AP z-value: 2.04, p-value:0.04) on the AMD-W of *C. acutus* with 95% confidence. The third GML was selected because it is the most robust with an explicative strength of 31.41% (AIC: 224.33). Models one and two were not considered because they presented lower robustness (AIC: 225.05, Pseudo R^2:0.66; AIC: 226.37, Pseudo R^2: 0.08, respectively).
- In the case of *C. crocodilus*, the most robust GLM obtained was the third one, with a high explicative strength of 87.76% (AIC: 154.84), and models one and two were discarded (AIC: 160.78, Pseudo R^2:0.63; AIC: 171.31, Pseudo R^2: 0.62, respectively). AMD-W for *C. crocodilus* was found to be influenced by more environmental co-variables, such as AT and IND with 99.9% confidence. As well as AP, SR, and Tmin with 95% confidence (z-value: 2.12, p-value: 0.33e-01; z-value: -2.01, p-value: 0.45e-01; z value: -2.42, p-value:0.16e-01).

Future/Follow-Up Work

Finally, the pilot study shows an approximation of the movement patterns and home ranges for *C. acutus* and *C. crocodilus* with VHF telemetry, specifically in a dry season for the localities of Arrecifes and Cañaveral in the eastern sector of the PNNT. Our findings provide a preliminary analysis of the distribution patterns of the locations obtained for the two sympatric species. We were able to identify that environmental co-variables (AP, AT, Tmin, SR) and the difference in individuals may influence the movements of crocodylians monitored for the 2021 dry season. We suggest continuing the monitoring project due to the importance of the PNNT as a protected area, being the second most visited by tourists nationwide. It is necessary to increase the number of individuals and the tracking time considering other climatic seasons, to avoid underestimating the area used by the populations of *C. acutus* and *C. crocodilus* in the eastern sector of the PNNT.

It is also necessary to improve the transmitter attachment system to avoid losing relevant information. On the other hand, a warning is made to the park rangers of the ecotourism trails that overlap with the home ranges and greater incidence of the study species. This data provides a technical resource to the National Parks of Colombia for the conservation of these species within the PA, as well as for the protection of their associated ecosystems and also to prevent negative interactions between crocodylians and humans. Likewise, the findings reduce the information gap that exists at the national and regional levels on the spatial ecology of *C. acutus* and *C. crocodilus*, we hope that this pilot work may help to start new monitoring projects of crocodylians with radiotelemetry in the country.

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