KIRSTEN M. SILVIUS,

RICHARD E. BODMER,

AND JOSÉ M.V. FRAGOSO,

EDITORS

PEOPLE IN NATURE

Wildlife Conservation in South and Central America

People in Nature

WILDLIFE CONSERVATION IN SOUTH AND CENTRAL AMERICA

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Abundance, Spatial Distribution, and Human Pressure on Orinoco Crocodiles (*Crocodylus intermedius*) in the Cojedes River System, Venezuela

ANDRÉS E. SEIJAS

Crocodilians in general, and the Orinoco crocodile (*Crocodylus intermedius*) in particular, have been traditionally hunted by both aboriginal and rural people in Venezuela because of their value as a food resource or because of the putative medicinal or magical properties of their teeth and fat (Petrullo 1939; Codazzi 1940; Tablante-Garrido 1961; Gumilla 1963). The first attempt to commercialize crocodile skins in Venezuela was initiated in 1894–1895 by a U.S. company that established its headquarters in El Yagual, in Apure state (Calzadilla 1948; Medem 1983). At that time crocodiles were hunted with firearms during the day, a highly inefficient method in which many dead and injured animals could not be recovered from the river. That early commercial enterprise failed. The expenses of preparing and transporting the hides proved to be so great that the work had to be abandoned (Mozans 1910; Calzadilla 1948). Despite this early commercial exploitation, during the first quarter of the twentieth century the Orinoco crocodile was probably as abundant as it was when Humboldt (1975) and other nineteenth-century naturalists were amazed by its numbers.

A new phase of commercial exploitation started at the end of the 1920s (Medem 1983). New hunting methods (flashlights and harpooning) and an international demand for crocodilians hides combined to bring to the brink of extinction in less than three decades a species that originally could be counted in the millions. The peak of the exploitation occurred in 1930–1931, when between 3,000 and 4,000 skins were traded daily in San Fernando de Apure. From 1933 to 1935 Venezuela exported 900,000 crocodile hides. The large-scale exploitation ended in 1947–1948, due mostly to the scarcity of the resource by that time. Independent hunters persisted in this activity for several years, but the export of C. *intermedius* hides from 1950 to 1963 was minimal (Medem 1983).

Commercial exploitation extirpated the Orinoco crocodile from most of its historic distribution range (Godshalk 1978; Medem 1981, 1983; Thorbjarnarson 1992; Ross 1998). Today, the Orinoco crocodile is one of the most threatened crocodilian species in the world (Ross 1998). The species is listed as critically endangered in the Venezuelan Red Data Book (Rodriguez and Rojas 1995). Although *C. intermedius* has been legally protected both in Colombia and Venezuela for more than thirty years and although international trade has been prohibited by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) since the middle 1970s (King 1989), little recovery of wild populations has occurred.

Even though commercial exploitation of Orinoco crocodiles in Venezuela is today probably negligible, occasional killings of individuals still occur because they are considered vermin. Also, they are hunted for their meat or fat, and their eggs and hatchlings are collected as food or pets, respectively.

Currently, the most important, and probably the only viable, populations of the Orinoco crocodile (Arteaga et al. 1997) are found in two areas of divergent characteristics in Venezuela. First is the Capanaparo River in the state of Apure (Godshalk 1978; Thorbjarnarson and Hernández 1992), a prime-quality habitat, more than 100 m wide, that is impacted relatively little by human activities and that is in the center of the species' range, where it reached its historically highest densities. Second, in the states of Cojedes and Portuguesa is the Cojedes river system (CRS), a set of highly modified and contaminated narrow river sections (in general less than 20 m wide), near the periphery of the distribution of the Orinoco crocodile and very close to some of the most important agricultural, urban, and industrial centers in the country (Ayarzagüena 1987, 1990; Seijas and Chávez 2000).

Although the survival of the Orinoco crocodile in a river like the Capanaparo is easy to understand, the presence of a dense population of this species in the CRS is somehow paradoxical. One of the factors that may explain the survival of *C. intermedius* in the CRS (Ayarzagüena 1987) is the isolation in which that region remained during the years of intense commercial exploitation of the species (1929–1945). The CRS today is, however, not as isolated as it was in the recent past. Some areas of the river are closer to human population centers, and presumably under greater human pressure, than others. Human population in the CRS is mostly concentrated in the north, close to the piedmont of the Coastal Range. The southern part is sparsely populated by humans, with El Baúl (5,236 inhabitants) the most important town. Is this distinct pattern of human occupation of space a factor that could explain the current distribution of the Orinoco crocodile in the CRS? In this paper I explore that possibility. My hypothesis is that human proximity negatively impacts crocodile survival, and consequently, crocodiles should be found more frequently in river sections far from human settlements.

STUDY AREA

For the purposes of this study, the Cojedes River System is defined as the middle and lower portions of the Turbio-Cojedes River basin. It covers a wide fringe of land along the Cojedes and Sarare Rivers. The study area in the CRS encompasses

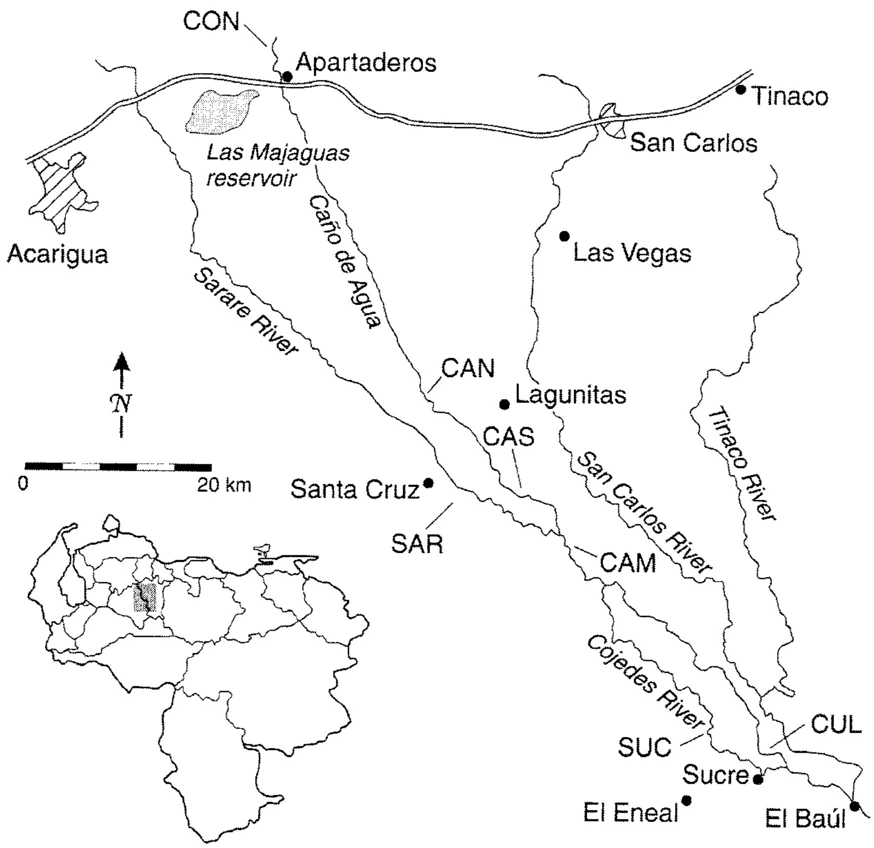

FIGURE 14.1 Cojedes River System, Venezuela. Rivers flow toward the south. Major cities are located in the north, whereas the south is sparsely populated. The acronyms indicate the locations of the river sections surveyed: CON, Cojedes Norte; CAN, Caño de Agua Norte; CAS, Caño de Agua Sur; SAR, Sarare; CAM, Caño Amarillo-Merecure; SUC, Sucre section; and CUL, Caño La Culebra.

the cities of Acarigua and San Carlos to the north and extends southeast to the confluence of the main course of the Cojedes River with Caño Amarillo-La Culebra near the town of El Baúl (fig. 14.1).

In the northern part of the CRS, agricultural lands dominate the landscape and are interspersed with large- and medium-sized urban centers and cattle ranches. The southern part of the region (south of the Lagunitas-Santa Cruz road) is a matrix of forested savannas and cattle pastures intermixed with forest relicts, scattered agricultural lands, wetlands, and other less extensive land-cover categories. The CRS has zones of relatively high human population densities in the north, where the cities of San Carlos (> 80,000 people) and Acarigua (~ 200,000 people) are located and where the rivers have been modified by damming, canalizing, dredging, contamination, and deforestation. In the south the rivers retain more of their original conditions, and El Baúl (6,000 people) is the largest town.

METHODS

Based on two landsat TM satellite images of the study area, taken on January 10 and February 27, 1990 (early dry season), and on data from more than 1,500 GPS locations, I updated the previously existing cartographic information of the region. The basic land cover features considered for mapping were agriculture, pasture lands and open savannas (taken together as a unit), urban areas, water bodies, forests, permanent rivers, and roads. Maps were converted into raster images for Geographic Information System (GIS) analyses (IDRISIS 1997). The initial raster image generated from the classification of the satellite images had a spatial resolution of 32 x 32 m. Because of the extension of the land surface being modeled (9,660 km^2) and in order to speed up the GIS analyses, the raster images used for the final analyses had a spatial resolution of 64 x 64 m.

With the GIS I generated a cost-distance (CD) layer for every major city as well as for small towns, villages, and other human settlements located close to the river. Each CD layer modeled the cost of movement from a particular human settlement to any location on the landscape, i.e., it represented the ease with which people could reach every spot in the study area, considering the friction offered by different land-cover types. The value assigned to a pixel in the CD layer was a function of its distance to the human settlement under consideration and of the friction exhibited by the land surface between them.

The friction surface used to calculate the cost-distance layer was generated according to the relative cost shown in table 14.1. Primary roads were assigned a friction of 1. This value, in fact, means that there was no cost for travel by car on that surface and that cost-distances measured along them were equivalent to Euclidean distances. Because it is possible to travel on average at 80 km/h on primary roads, the friction values assigned to other land-cover types were calculated relative to how much longer it takes to travel an equivalent distance on or through them (using the fastest transportation method that can be used on that surface). Friction values assigned to rivers were somewhat arbitrary but larger than the values assigned to most land-cover surfaces in order to reflect the fact that they are important obstacles to human movements (although river sections that are navigable facilitate human movements). The highest friction was assigned to lakes, which were considered barriers to human movement for the purposes of this study.

The CD layer obtained for each town or city was used to model the presumed human pressure exerted by that city on every reach of the Cojedes River system (indeed, on every location within the study area). The human pressure index (HPI) is a value that indicates the strength of the expected impact of a particular urban area on every point (pixel) in its surrounding landscape. The HPI of a particular spot (i.e., pixel in the raster layer) was calculated as a function of its proximity to human settlements and of the human population size of these particular human settlements. That river reaches close to cities and towns were assumed to be under greater human pressure than river reaches located farther from those urban areas.

TABLE 14.1 Relative Cost of Movement (friction) Through Different Land Cover Types in the Study Area

LAND COVER TYPE	MEAN SPEED (KM/HOUR)	RELATIVE FRICTION
Primary roads	80	1.00
Secondary roads	60	1.33
Improved roads	40	2.00
Dirty roads	20	4.00
Urban areas	35	2.29
Main rivers	—	80
Secondary rivers	—	60
Intermittent rivers	—	40
Agriculture fields	—	20
Savannas	4	20
Forests	2	40
Lakes	—	100

Note: See text for calculation of friction values. The high friction value assigned to river may not apply to navigable river sections.

On the other hand, large cities were expected to exert a higher pressure than small ones. Mathematically,

$$HPI_i = P_i \cdot CD_i^{-2} \quad (1)$$

where P_i is the population size of a particular human settlement and CD_i is the cost-distance layer obtained for that particular human settlement. Equation 1 is in essence a particular case of a gravity model (Forman 1995), which states that the movement or interactions between two nodes increase with node size but decrease with the square of the distance between nodes. In my case one of the nodes (the pixel for which the *HPI* was been calculated) received, arbitrarily, a unit free value of 1. The *HPI* as expressed in Equation 1 has the units of density (inhabitants/km^2).

The urban centers considered in the model are listed in table 14.2. Many other small villages (among them, Retajao, El Estero, and La Palmita) and cattle ranching operation centers (including La Batea, Merecure, and Las Guardias) were used to generate cost-distance surfaces. Because of a lack of precise information on human population size in these human settlements, I assigned a figure of 500 inhabitants to small villages and hamlets and 100 to the cattle ranching operation centers.

Because any particular point on the study area may be simultaneously under the influence of several human settlements, the layer of Total Human Pressure (THP) of the entire study area was obtained adding the HPI_i layers of all these settlements (fig. 14.2). In this way every pixel, including those representing the rivers, had an associated *THP* value. Mathematically,

TABLE 14.2 Towns and Other Human Settlements in the Cojedes River System, Venezuela, Used to Model the Human Pressure in the Study Area

TOWNS	NUMBER OF INHABITANTS
Portuguesa state	
Acarigua-Araure	171,850
Agua Blanca	9,393
San Rafael de Onoto	7,206
Pimpinela	4,563
Santa Cruz	4,090
Cojedes state	
San Carlos-Tinaco	68,325
Las Vegas	6,897
El Baúl	5,236
Apartaderos	4,260
Cojeditos	4,911
Lagunitas	3,353
Sucre	1,886
El Amparo	1,105

Note: The number of inhabitants is based on OCEI (1993).

$$THP = \Sigma HPI_i \qquad (2)$$

In the CRS several river sections, ranging from 5.2 to 16 km, have been repeatedly surveyed since 1991 (Seijas 1998; Seijas and Chávez 2000). In 1996 and 1997 the position of most crocodiles seen in those river sections during nocturnal spotlight surveys was recorded with a GPS. The GPS locations for those surveys with the highest number of crocodile sightings were used to generate a new map layer. The THP of the spot (pixel) in which each crocodile was seen was obtained by overlaying the crocodile locations layer on the THP layer.

For all surveyed river sections the frequency of pixels with a particular THP value was calculated and tabulated in ranges. That gave an indication of the availability of river habitat under different THP values and allowed the calculation of the number of crocodiles expected to be found in each of these THP ranges. Chi-square analyses (G^2, likelihood ratios; Sall and Lehman 1996) were used to compare frequency distribution of THP of crocodile sightings in relation to the frequency distribution of THP for the surveyed river sections.

To assess the importance of other human-related factors in determining the abundance of crocodiles in the CRS, I performed a nonparametric correlation analysis between crocodile density in each river section (table 14.3) and the rela-

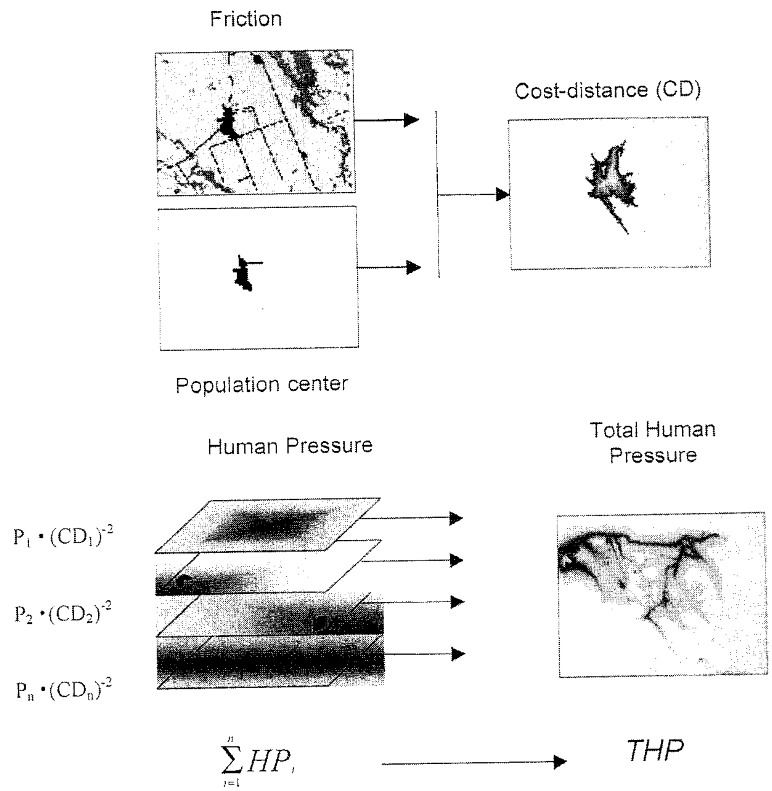

FIGURE 14.2 Flow chart indicating the procedure followed to obtain the Total Human Pressure (THP) over every place in the study area. From a friction surface and each population center a cost-distance (CD) surface was generated using a geographic information system. The population size of each town, divided by the CD^2, allowed the calculation of the human pressure (HP) it exerted over every place in the study area. The Total Human Pressure was calculated adding the HP of all population centers.

tive importance of the following variables: isolation from human populations, navigability, and contamination. I ranked each river section according to the relative importance of these variables (table 14.4). Information on isolation from human population was obtained from data in table 14.3. Ranking according to contamination was based of information presented by Campo and Rodríguez (1997) and Seijas (1998).

Regarding navigability, the only river sections that are navigated on a regular basis are those close to Sucre (SUC) and, to a lesser extent, La Culebra (CUL). For people living in Sucre and El Baúl, the Cojedes River is an essential means of year-round communication with cattle ranches. There is also commercial and subsistence fishing and, presumably, illegal spectacled caiman (*Caiman crocodilus*)

TABLE 14.3 Total Human Pressure (THP) and Mean Crocodile Population Index in Surveyed River Sections of the Cojedes River System, Venezuela

RIVER SECTION	LENGTH (KM)	MEAN THP (INH./KM^2)	RANGE THP	MEAN CROCODILE DENSITY (IND./KM)*
Cojedes Norte (CON)	7	15.6	7–56	2.0
Caño de Agua Norte (CAN)	16	7.2	1–100	4.4
Sarare (SAR)	8.4	11.7	1–78	3.1
Caño de Agua Sur (CAS)	5.2	2.0	1–6	7.3
Caño Amarillo-Merecure (CAM)	8.4	1.2	1–3	4.9
Sucre (SUC)	11.6	1.7	1–19	0.6
La Culebra (CUL)	12.8	1.0	1	1.4

Note: River sections are listed from north to south (from upstream to downstream).
*Taken from Seijas and Chávez (2000).

TABLE 14.4 Ranks of Crocodile Densities, Isolation from Urban Areas, Contamination, and Navigability of the Different River Sections That Were Surveyed in the Cojedes River System, Venezuela

RIVER SECTION	CROCODILE DENSITY	ISOLATION FROM HUMANS	CONTAMINATION	NAVIGABILITY
Cojedes Norte (CON)	5	7	1	6.5
Caño de Agua Norte (CAN)	3	5	2	6.5
Sarare (SAR)	4	6	5	4
Caño de agua Sur (CAS)	1	4	3	5
Merecure-Caño Amarillo (CAM)	2	2	4	3
Sucre (SUC)	7	3	6	1
La Culebra (CUL)	6	1	7	2

Note: Contamination ranks were based on information presented in Campo and Rodriguez (1997) and Seijas (1995). Navigability is based on personal observations.

hunting around Sucre and in La Culebra. Upriver from Sucre the river section Merecure-Caño Amarillo (CAM), although navigable year round, seems to be navigated only sporadically since only one family with a small canoe was observed there. Caño de Agua Sur (CAS) is difficult to navigate because of obstructions created by fallen trees and urban debris and garbage that drift from upstream towns.

That section seems to be occasionally visited and sporadically navigated by hunters and campers. The Sarare (SAR) river section surveyed are in the same situation as CAM. Caño de Agua Norte (CAN) and Cojedes Norte (CON) are rarely, if ever, navigated by people other than myself and other crocodilian researchers.

RESULTS

A tri-dimensional representation of the THP in the study area is shown in Figure 14.3. As would be expected, the highest THP, represented in the figure as high elevation plateaus, was located in and around the main cities (Acarigua and San Carlos). Consequently, the river reaches flowing through densely human populated areas were under relatively high human pressure (table 14.3). Cojedes Norte (CON) for example, which is very close to the towns of Apartaderos and San Rafael de Onoto, had THP ranging form 7 to 56 (mean 15.6, the highest of all surveyed river sections). At the other extreme, THP was relatively low near Sucre (SUC) and especially so in La Culebra (CUL), where all the pixels representing the river had THP of 1 (table 14.3).

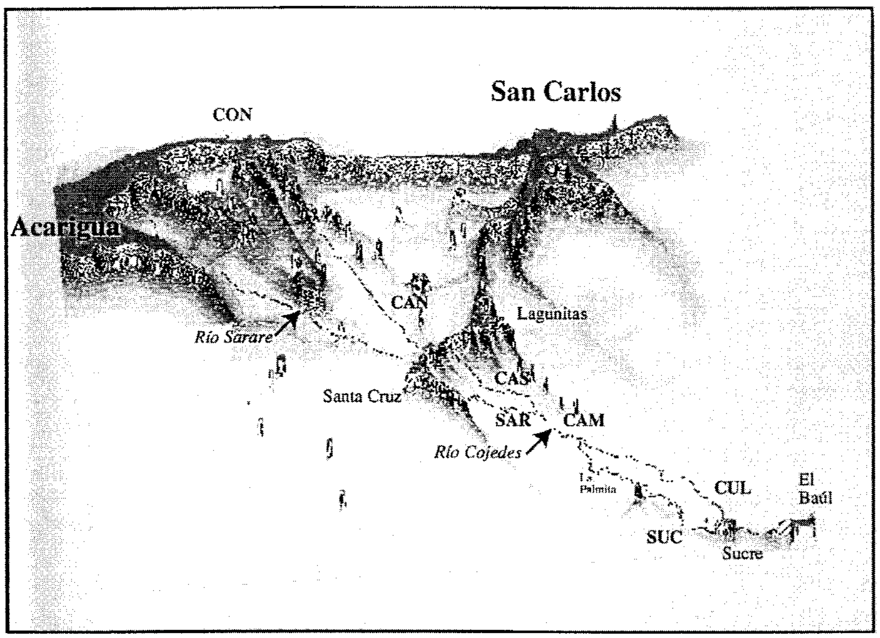

FIGURE 14.3 Tridimensional representation, generated with the software IDRISIS, of Total Human Pressure (THP) on the Cojedes River System, Venezuela. Areas in clear gray or white are under low human pressure (THP < 2). Different tonalities of gray (elevation) represent the intensity of human pressure, with the highest THP (> 100) in dark gray found in towns and cities represented as plateaus. Acronyms indicate the locations of the river sections surveyed (see fig. 14.1).

According to my hypothesis, crocodile sightings should be more frequent in river spots (pixels) under relatively low THP. An analysis of the distribution of 226 nonhatchling crocodiles spotted in 1996 and 1997, according to the THP of the specific spot where they were observed (fig. 14.4, upper), indicated that, contrary to expectations, crocodiles were underrepresented in river spots (pixels) of very low human pressure (THP ranging from 1 to 2) (G^2 = 23.02, P = 0.002). That was a consequence of low densities of crocodiles in SUC and in CUL, the surveyed river

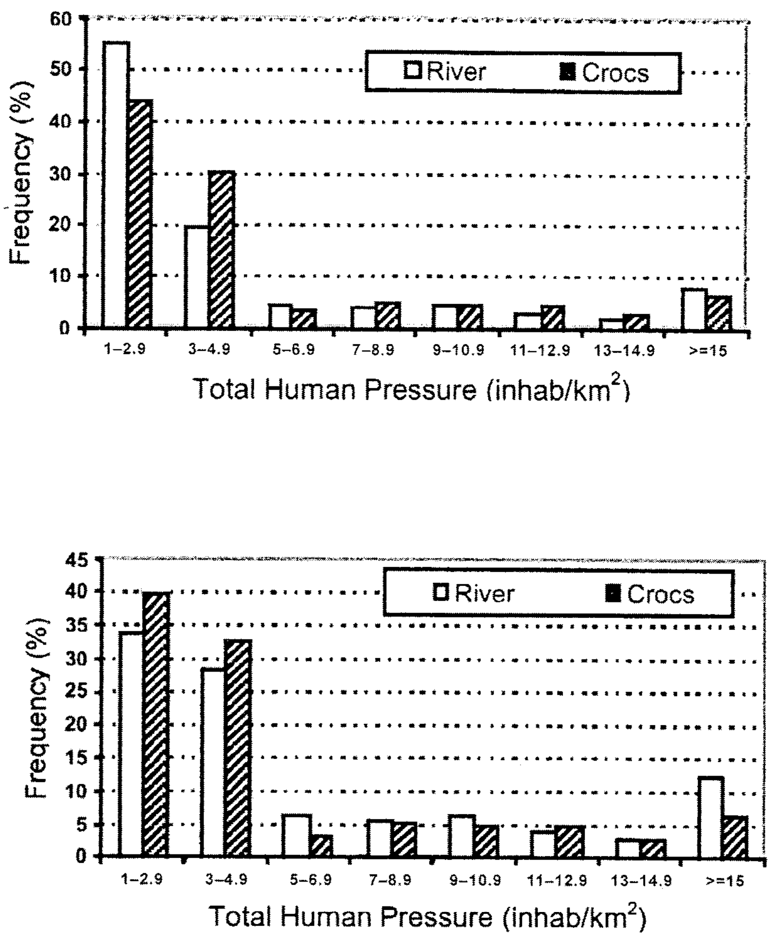

FIGURE 14.4 Frequency of crocodile sightings compared to the frequency distribution of human pressure in different river sections of the Cojedes River System, Venezuela. Bars labeled river represent percentage of pixels (64 x 64 m) in each range of human pressure (HP) along river sections surveyed. Bars labeled crocs indicate the percentage of crocodiles seen in pixels within a particular range of HP. Upper graph includes all river sections; bottom graph excludes navigable sections.

sections under the lowest THP, whereas crocodile densities were highest in such river sections under moderate THP as CAS (mean THP = 2, range 1 to 6). In contrast to other river sections surveyed, CUL and SUC are navigated year round. When data from these river sections were dropped from the analysis, the frequency distribution of THP of locations of crocodile sightings and THP of river reaches differed in the direction predicted by the hypothesis ($G^2 = 15.42$, $P = 0.03$) (fig. 14.4b). Within the nonnavigable sections crocodile abundances were negatively related to human pressure (Spearman Rho = –0.9, $P = 0.04$, $n = 4$) (fig. 14.5).

Correlation analyses indicate that the variable with strongest relationship to crocodile densities was navigability, but that correlation (negative) was not statistically significant (Spearman Rho = –0.505, $P = 0.248$). The correlation between isolation and crocodile densities was also negative but not significant (Spearman Rho = –0.11, $P = 0.8$), in agreement, as would be expected, with the THP analysis presented above.

DISCUSSION

Although the isolation of the Cojedes River may have played an important historical role in preserving a small population of Orinoco crocodiles (Ayarzagüena 1987),

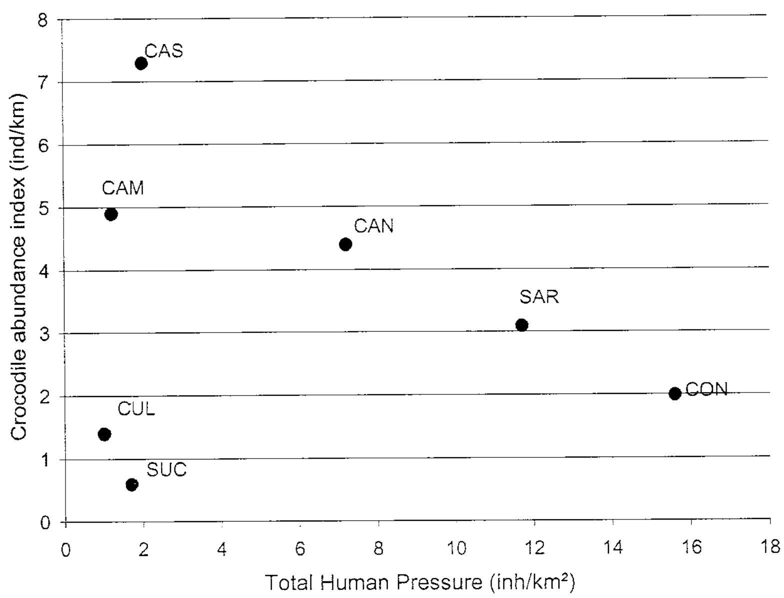

FIGURE 14.5 Relationship between mean Total Human Pressure (THP) and mean crocodile population index in river sections of the Cojedes River System, Venezuela. La Culebra (CUL) and Sucre (SUC) are the only river sections that are navigable.

today the river sections most isolated from human settlements showed the lowest crocodile densities, whereas the areas with the highest crocodile densities were moderately isolated from urban centers. Low densities of crocodiles in parts of the study area, such as those river reaches close to Sucre or in caño La Culebra, suggest that navigability and difficulty of access are probably important factors explaining the current pattern of distribution of the species in the CRS.

A combination of isolation from humans and impossibility of navigation have been used to explain the persistence of other small population of Orinoco crocodile in the Tucupido River (Ramo and Busto 1986; Thorbjarnarson and Hernández 1992). According to Thorbjarnarson and Hernández (1992) crocodiles in the Capanaparo River are protected during the dry season when low-water levels make it unnavigable.

Proximity to towns and cities seems to explain the abundance and distribution of crocodiles in river sections of the CRS, but future studies should include more river sections under relative high human pressure, such as the upper section of CAN near Cojeditos and some of the Sarare River close to Pimpinela and south to Agua Blanca. In some areas with high THP that were not properly surveyed at night. some crocodiles were observed. Seven crocodiles, for example, were seen on January 14, 1993 in Toma Cojedes, an area with a high THP of 46 to 48. In Retajao, a hamlet along the left margin of CAN, a nesting female and a subadult crocodile were observed in 1996 and 1997. The latter individual was sighted just across the street from an elementary school, a spot with a very high THP of 50.

Anecdotal information indicated that downstream from Sucre, and particularly downstream from El Baúl, where the Cojedes river is routinely navigated by two or three dozen small boats and canoes, Orinoco crocodile populations remain as low as they were almost twenty years ago when first evaluated by Godshalk (1978). Young crocodiles are seen occasionally in the Cojedes River near El Baúl (M. González pers. comm.). They probably represent transient individuals or individuals that have been carried downstream by the river during the peak of the rainy season. Some of these crocodiles are taken by people in El Baúl as pets. Others are presumably killed by fishermen, accidentally or deliberately, or move farther downstream toward the Portuguesa River.

Most reproduction of the Orinoco crocodile in the CRS takes place in the middle sections of Caño de Agua and lower Sarare (Seijas 1998), where the species is protected by the relative isolation from towns and difficulty in navigation. These river sections are population sources, in which more than forty females nest every year (Seijas 1998). My data also indicate that reproduction is poor or absent near Sucre and in La Culebra sections, some 50 or 60 km downstream from the previously mentioned sections. No crocodile nest has ever been observed in that area. Under the current circumstances, because of low reproduction and presumably high risk of being killed by people, the later mentioned river reaches are population sinks for the Orinoco crocodile.

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