**A Final Report on**

# "HOME RANGE AND DISPERSION OF AMERICAN CROCODILE (*CROCODYLUS ACUTUS*) PRE-JUVENILES IN PLAYA BLANCA, COIBA NATIONAL PARK: TELEMETRY"

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## INTRODUCTION

The American crocodile (*Crocodylus acutus*) is one of the largest Neotropical crocodylians. Over-harvesting by commercial skin hunters has exhausted crocodile populations in much of its range, and by the late 1960s several populations were nearly extirpated (Charnock-Wilson, 1970, Platt and Thorbjarnarson, 2000; Venegas-Anaya et al, 2014). Although this charismatic species has extended its range, and several efforts have been made to understand its ecology and natural history, the population ecology and its population genetics remain poorly understood (Mazzotii, 1985; Platt and Thorbjarnarson, 2000; Venegas-Anaya 2014). This is partly due to *C. acutus* occurring in a large number of aquatic habitats and partly due to the fact that its habitats are highly fractionated making ecological studies in the wild more difficult. *C. acutus* is primarily a coastal species, occurring in brackish habitats including tidal estuaries, coastal lagoons and mangrove swamps, but it frequently can be found in freshwater habitats including rivers, lakes and reservoirs (Brazaitis, 197 3; Thorbjarnarson, 1989, Platt and Thorbjarnarson, 2000; Cedeno-Vazquez et al., 2006). Recent molecular genetic and ecological studies (Venegas de Anaya, 2013) have shown that *C. acutus* is a complex of at least three different species: *C. acutus* Center America, *C. acutus* from the Caribbean region and *C. acutus* from South America Pacific (Ecuador and Peru). Studies on population structure, population dynamics, habitat use and dispersion patterns are needed today more than ever; in some parts of the range population numbers have recovered due to the establishment of legal protection, and the increased

population size and frequency of larger sized animals have increased human-crocodile conflicts in some ways making the conservation successes achieved by the establishment of the hunting ban now becoming a conservation problem.

Studies on *C. acutus* population structure, special distribution patterns and habitat use can take advantages of the advancement in the techniques of radio-telemetry for monitoring the activity of animals living in their environment. These studies allow collecting long-term data on biological temporal rhythms of many species and have also revealed changes in daily, tidal and seasonal levels of activity and plasticity in circadian aspects (Tester and Figala 1990; Kay, 2004; Brien et al., 2008; Fujisaki et al., 2014). Data on home-range and overall distribution are critical for understanding ecological processes and advising decision makers on ways to improve conservation programs, particularly for focal (keystone) species that play crucial roles in shaping ecosystem function in critical areas of biodiversity conservation (Brien et al., 2008; Fujisaki et al., 2014). Although we have found several studies on crocodiles radio-telemetry, we only could find two studies on American crocodile: Rodda (1984) and Kushlan and Mazzotti (1989). Rodda (1984) reported on the movement patterns of ten juveniles of American crocodile in Gatun Lake, Panama, using radio telemetry for two months during the summer of 1981. He spatially geo-referenced 233 points that followed 80% of the movements of individuals restricted to areas with core distribution of less than 200 meters. He also found that the signal strength of the transmitter is reduced drastically when the individual is immersed in water and determined that the movement of juveniles is much higher during the day compared to the night (65%); furthermore, movements are restricted considerably at night with a full moon. Kushlan and Mazzotti (1989) focused on *C. acutus* populations in southern FL to better explain nesting ecology of the species, using observational and telemetry data from 10 individuals. They found that females returned to the same area to nest almost every year, and that their movements varied seasonally. For American crocodiles, radio-telemetry allows one to study species requirements for a specific area, season, sex and age-class. Knowledge of the amount and type of space required by animals differing in sex, age and in different seasons is necessary to better apply CITES regulations for reintroduction of endangered or threatened species. It is also necessary to reduce crocodile-human conflicts by the successful translocation of problem animals and as well as to help crocodile farmers find a manageable, local wild population from which to obtain new 'breeders' (Thorbjarnarson and Hernandez 1992; Kay 2004). This is true for most of the Central American countries, but is especially relevant to Panama where besides the presence of a number of American crocodile farms and the increased human-crocodile conflicts there are megaprojects currently being developed that require the translocation of animals on a large scale (Panama Canal expansion).

In order to gather information about the dispersion patterns and the minimum environmental habitat conditions that American crocodiles require and to better understand the species' population ecology in marine-coastal environments, a long term ecological study was initiated in 2009 by Texas Tech University (TTU), the Smithsonian Tropical Research Institute (STRI), the Panamanian National Environment Authority (ANAM) and the Crocodile Specialist Group (IUCN-SSC-CSG) with the support of National Secretariat for Science, Technology and Innovation of Panama (SENACYT). As part of this project, we established a radio-telemetry pilot study from October to December 2010. Our aims were to: (1) Standardize a radio-telemetry protocol to be applied on a larger scale in the study of the reproductive ecology of the species in

Coiba National Park and its continental buffer zone in the Gulf of Chiriquí, Panama. (2) Determine the home range of four *C. acutus* sub-adults (TL 90-180 cm) and one adult (>180 cm) from Playa Blanca at Coiba Island in Panama; and 3) Describe the most important biotic and abiotic environment factors of the habitat associated with *C. acutus* sub-adults in Playa Blanca at Coiba Island in Panama.

## METHODOLOGICAL APPROACH

The study was conducted in the southeast of Coiba Island, Panama from Boca Grande to Punta Felipa. Coiba is one of the 39 islands included in the World Heritage site, Coiba National Park, part of the Eastern Tropical Pacific Marine Corridor (Figure 1).

Five sub-adults (one female and four males) were chosen randomly, captured and tagged on the back of the neck with a 12.5 gm radio transmitter (125 MHz) manufactured by TELENAX using Kay, 2004 modified method (www.telenax.com; Kay, 2004; Figure 2). Morphological measurements were taken and the general health of each individual was registered. Animals were radio-tracked using a unidirectional three element antenna, YAGI, which perceives the signal emitted by the transmitter "TELENAX, RX-TLNX". Over the first 72 hours, animals were radio-tracked along 10.5 km transect every three ours and every 24 hours their physical location was noted. After the first three days, animals were followed twice a day for 15 days every month from September through December, 2010. We located each animal with the antenna and estimated its most probably geographical location using the triangulation method of three lines created by projecting geographical points on the azimuth line. Geographic points were recorded using a Garmin eTrex 10 GPS. Points were separated from one another by an angle of approximately $45^{o}$.

Crocodile habitat was assessed on the basis of land cover cartography developed at the Smithsonian Tropical Research Institute (STRI), National Environmental Authority, and the Tommy Guardia National Geographic Institute (ANAM, 2009) and the geographic coordinates of the capture sites. Land covers were defined as: lowlands, flooding areas, mangrove areas, beaches, rivers, and fresh water bodies of marine coastal habitats in CNP. Marine coastal habitats in CNP are influenced by dramatic tide changes from 2.5 m up to 7.5 m every 6 hours (Venegas-Anaya et al, 2014).

We also made a "quick and dirty" estimate of population sizes for the area using waking spot light surveys on transects of 10.4 km and three meters wide (Messel et al. 1981; Magnusson 1982; Wood et al. 1985; Platt and Thorbjarnarson 2000). We started approximately 15 to 30 minutes after sunset (Messel et al. 1981; Platt and Thorbjarnarson 2000). Following methods described in Platt and Thorbjarnarson (2000), *Crocodylus acutus* individuals were approached in close enough proximity to allow more accurate estimation of total length (TTL) of the animal based on the distance between the eyes (Magnusson 1983).

### Data Analyses

Telemetry data was recorded into an excel database (Tables 1, 2, 3 and 4). Using model-builder tools from ArcMap 10.2 software (Esri, 2013), we generated a model divided into three parts to

analyze the telemetry data. The first part of the model had the function of drawing virtual vectors from azimuth data (i.e., the heading), coordinates (e.g., N, W) and the distance (in meters) generating area-like polygons from the cut points of said lines. We then calculated the centroid point, which is the actual location of the monitored animal. The second part of the model consisted of creating an empty file, "shp" format where the information of the points generated by the third part of the model will be inserted. The last part of the model was design to calculate a centroid point from the centers of the resulting average geometric figures breakpoints of virtual lines generated in the first step of the model (Figure 3).

With the calculated positions and using Minimum Convex Polygon from Home Range Tools for ArcGIS® (HRT) we calculate the area used and visited by each animal in four months of rainy season. To calculate the minimum convex polygon, we used the average fixed account with a 95% point selection. This method calculates the average of the X (longitude), and Y (latitude), selecting the set of closest points to the arithmetic mean considering the percentage of selection.

We also use Kernel function from HRT to visualize animal presence in an area and to estimate the home range of each animal following the parameters of Rogers (2011_ and Kie (2010). The Kernel Density tool calculates the density of features in a neighborhood around those features. It can be calculated for both point and line features.

## RESULTS

We captured five individuals (one female and four males). Individuals were given unique identification numbers (ID's). They were labeled by notching both the single and double scales of the tail before release (Webb, 1977). Individuals label were MVCO82 (male), MVCO84 (male), MVCO100 (female), MVCO105 (male), and MVCO106 (male). Each individual was successfully tagged and marked with a radio transmitter (Figure 2, panels C, D, E and F). We lost individual MVCO106 after the first week of the experiment; as a result, we did not include this individual in any of the further analyses.

After several trials, we finally developed a Model-Builder (ArcMap 10.2 software) for estimating an individual's position by the triangulation method (Figure 3). Individual MVCO82 was a male capture at point -81.66278 Longitude (Lon) 7.38620 Latitude (Lat) with total length of 92.90 cm For MVCO82 we had 48 monitoring events over four months and obtained 144 geographic points from which, we got 43 individual locations using the Model-Builder (Table 1). The longest distance traveled was 2.8 km. This individual spent the vast majority of his time (97.7%) nearby to the point -81.662 7.386. his home range calculated by the Minimum Convex Polygon (MCP) function and equaled 24,908.6 $m^2$ (Figure 4). Kernel analysis showed that individual MVCO82 occurred on an area of 26,530.5 $m^2$ and the denser core area, was estimated to be 6,134.5 $m^2$ (Figure 4). MCP home-range calculations did not include one projected point (-81.667622 and 7.387799). Kernel analysis did not include three projected points to calculate the home-range: (-81.667622 and 7.387799; -81.661523 and 7.383938; -81.661795 and 7.383329). This individual spent most of his time at the mangrove area close to a fresh water stream highly

influenced by the tide. The core of the area was 42.5 m. back from the beach. Only once was this crocodile found 23.8 m into the sea.

Individual MVCO84 was a male captured at point -81.659590 (Lon) and 7.387240 (Lat) with a total length of 123.50 cm. For this individual we had 56 monitoring events over four months and obtained 168 geographic points from which, we got 47 individual locations using our Model-Builder (Table 2). The longest distance traveled was 0.356 km. Home range calculated by the Minimum Convex Polygon (MCP) function was 36,908.3 $m^2$ (Figure 5). Kernel analysis suggested that individual MVCO84 occurred over an area of 31,669.7 $m^2$ and the denser core area was 23,297.6 $m^2$ (Figure 5). Although Kernel analysis included all projected points, MCP did not include two projected points to calculate the total area used by the individual: -81.67 and 7.391; -81.667622 and 7.387799. This individual spent most of his time near the mangrove area close to the fresh water stream highly influenced by the tide. The core of the area was divided by line of secondary forest and the individual was found at the side of this line most of the time. MVCO84 was found three times venturing into the sea, as far as 452 m.

Female MVCO100 was captured at point -81.669280 (Lon) and 7.386390 (Lat) with a total length of 108.90 cm. For this individual we had 45 monitoring events over four months and obtained 135 geographic points from which we derived 37 individual locations using our Model-Builder (Table 3). The longest distance traveled was 0.853 km. Home range calculated by the Minimum Convex Polygon (MCP) function was 45,3237.2 $m^2$ (Figure 6). Kernel analysis suggested that female MVCO100 occurred over an area of 867,273.8 $m^2$ and the denser core area was estimated to be 15,755.6 $m^2$ (Figure 6). Both, MCP and Kernel analysis did not include the projected point -81.682335 and 7.39173 to calculate the individual home-range. This individual spent most of her time in a core that includes a rocky coast. We found this individual in the sea nine times; this individual was found more times in the sea than any other.

Male MVCO105 was capture at point -81.700520 (Lon) and 7.412570 (Lat) with total length of 154.00 cm. For this individual we made 49 monitoring events in four months and obtained 144 geographic points from which, we got 40 individual locations using our Model-Builder (Table 4). The longest distance traveled was 3.3 km. The home-range calculated by the Minimum Convex Polygon (MCP) function was 2,374,533.2 $m^2$ (Figure 7). Kernel analysis showed that male MVCO105 occurred over an area of 14,273,879.5 $m^2$, with a denser core area, that was 47,7200.7 $m^2$ (Figure 7). MCP analysis did not include the projected points -81.731318 and 7.444227; -81.694918 and 7.408893 to estimate the individual home-range. This individual spent most of his time at two mangroves areas. One of the core areas is a lowland cover with mangroves and also with *Prioria capaifera.* The other core area includes a rocky coast. We could not ever find this individual in the sea.

## DISCUSSION

In figure 8 we show that individuals are territorial, living most of the time in the same core area. Individuals do not share their home-range, but male individual MVCO82 travels across of the female MVCO100 home-range at least one time. MVCO82 (92.90 cm) was the smallest animal and also had the smallest Home-Range. It seems that the size of home-range correlates with the size of the animals but we need more data to corroborate this hypothesis (MVCO84=123.50 cm;

MVCO100= 108.90 cm; MVCO105=154.00 cm). Animals seemingly spend most of the time in shadowy areas covered by mangrove forest.

Home-range calculated with MCP is always smaller than home-range calculated by Kernel analysis when we include all concentric circles as home-range (area in which an animal lives and travels). Although, the denser core area identified by Kernel function is the place where the animals spend the vast majority of time and where they eat, it does include the area where animals are only foraging. The core area for Kernel analysis is always smaller than the MCP area because the MCP area includes 95% of places visited by the animal. In Panama, October to December is the rainy season and animals have plenty of food and fresh water, this could be the reason why animals did not travel more and did not share their home ranges.

We found that it is very important to divide the area in smaller transects to facilitate data collection and reduce the tidal influence. Furthermore, we think that we should have fixed stations to localize individuals using the antenna. Fixed stations at every 50 meters or so will reduce the error and could make it easier to localize individuals. We feel that the most common error was taking the azimuth.

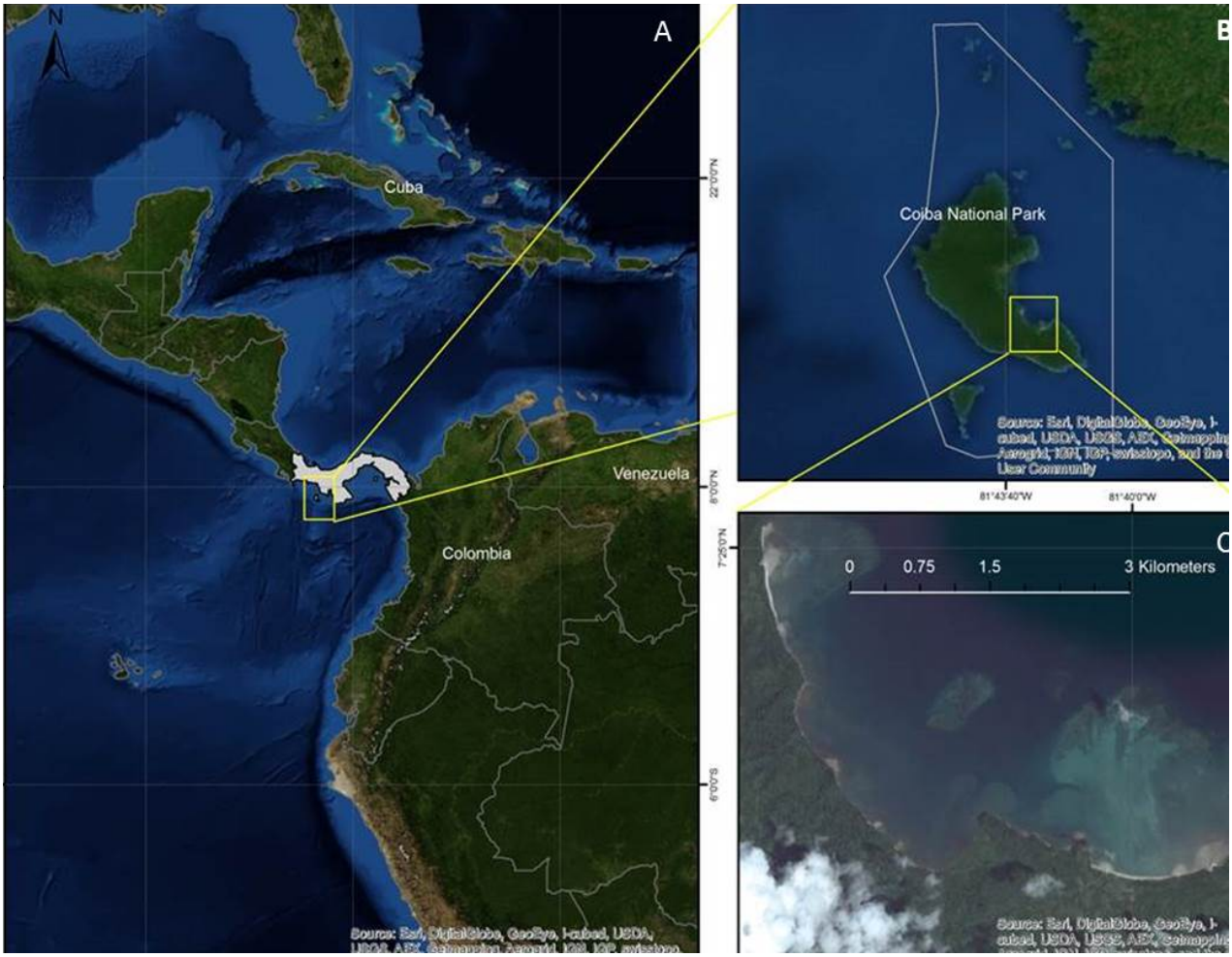



Figure 1. Area of study. Panel A shows Coiba Island location with respect to Panama, and Central America. Panel B shows the limits of Coiba National Park limits and the study area from Punta Felipa to Boca Grande. Panel C shows local area of the study.




Figure 2. Five sub-adults (one female and four males) were chosen randomly (Panels C, D, E and F), captured and tagged on the back of the neck with a 12.5 gm radio transmitter (125 MHz) manufactured by TELENAX (Panel A). Unidirectional three elements antenna YAGI that perceives the signal emitted by the transmitters and the receiver sends Model "TELENAX, RX-TLNX" (Panel B).

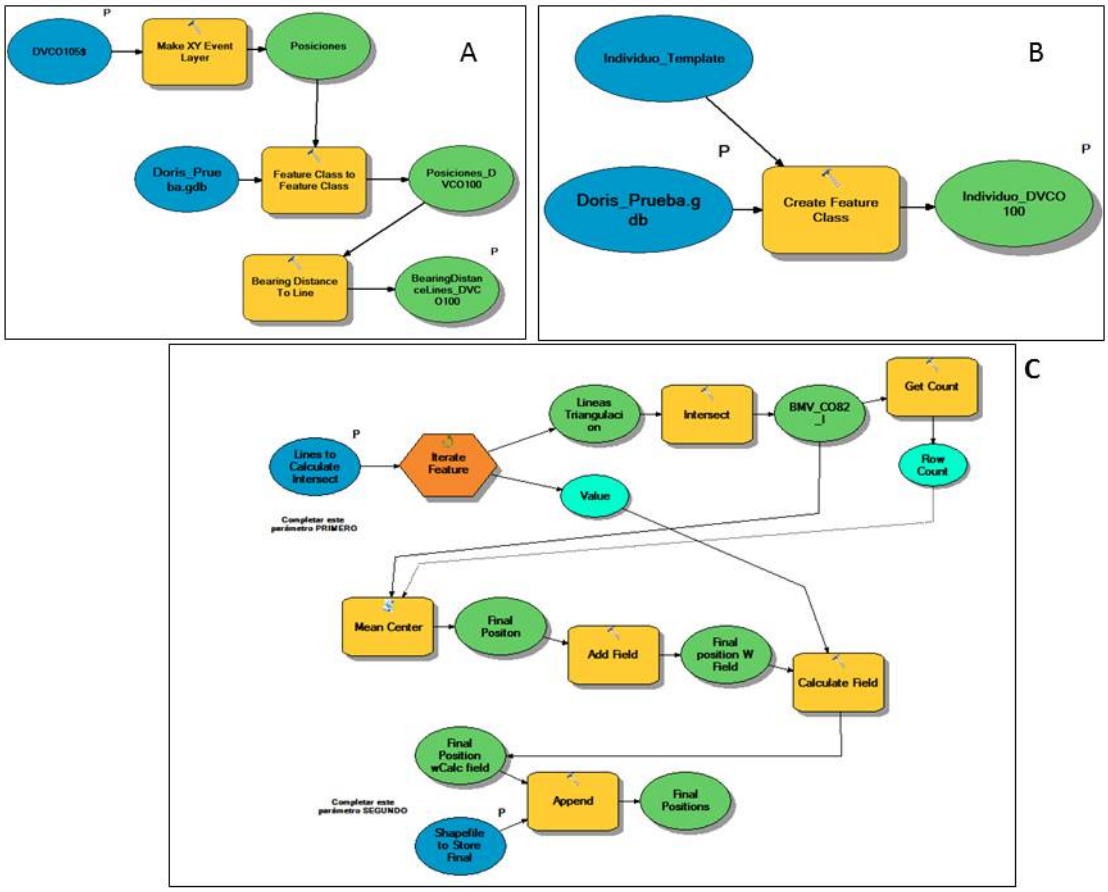



Figure 3. ArcMap 10.2 Model Builder was employed to automatically obtain the geographic position of individuals tagged with radio telemetry devices. Panel A= model 1 to obtain Bearing Distance Lines; Panel B= model 2 to create an empty file, "shp" format where the information of the points generated by the third part of the model will be inserted; Panel C= model 3 to calculate a centroid point from the centers of the resulting average geometric figures breakpoints of virtual lines generated in the first step of the model.

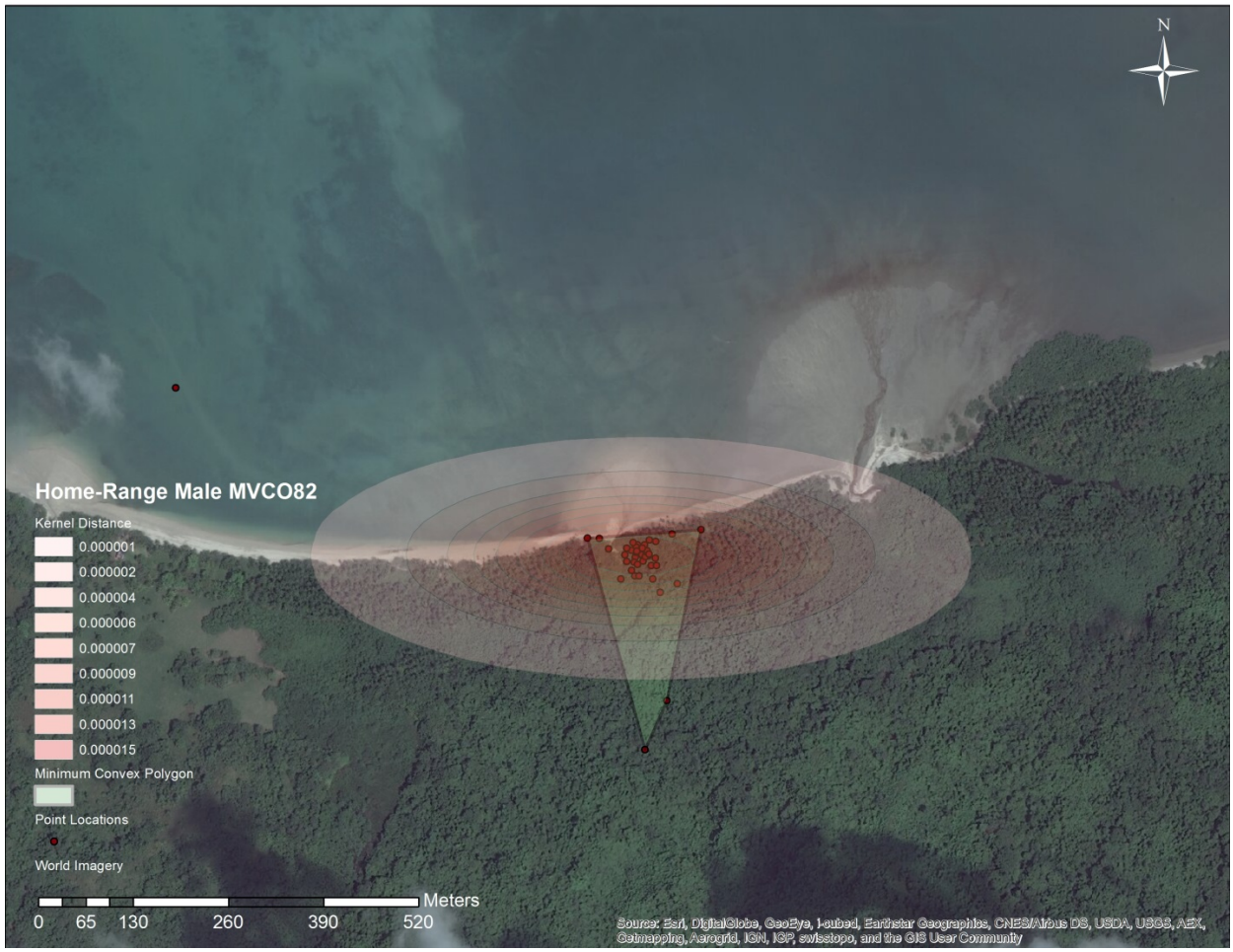



Figure 4. Home-range estimate for crocodile MVCO82. Red dots represent individual positions from October to December 2010. Concentric circles represent the result of Kernel analysis to calculate individual MVCO82 home-range. The center in red shows the most dense area (Area were individual spend most of his time). The triangle represents the MVCO82 Home-Range Minimum calculated using Convex Polygon analysis to function in ArcMap 10.2. The map of the area represents a compilation taken from Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. This World Imagery provides one meter or better satellite and aerial imagery for many parts of the world and lower resolution satellite imagery worldwide. The map includes 15m TerraColor imagery at small and mid-scales (591M down to 72k) and 2.5m SPOT Imagery (288k to 72k) for the world, and USGS 15m Landsat imagery for Antarctica. The map features 0.3m resolution imagery in the continental United States and 0.6m resolution imagery in parts of Western Europe from Digital Globe. In other parts of the world, 1 meter resolution imagery is available from GeoEye IKONOS, i-cubed Nationwide Prime, Getmapping, AeroGRID, IGN Spain, and IGP Portugal. Additionally, imagery at different resolutions has been contributed by the GIS User Community. For more information on this map, including the terms of use, visit us <a href="http://goto.arcgisonline.com/maps/World_Imagery " target="_new" >online</a>.

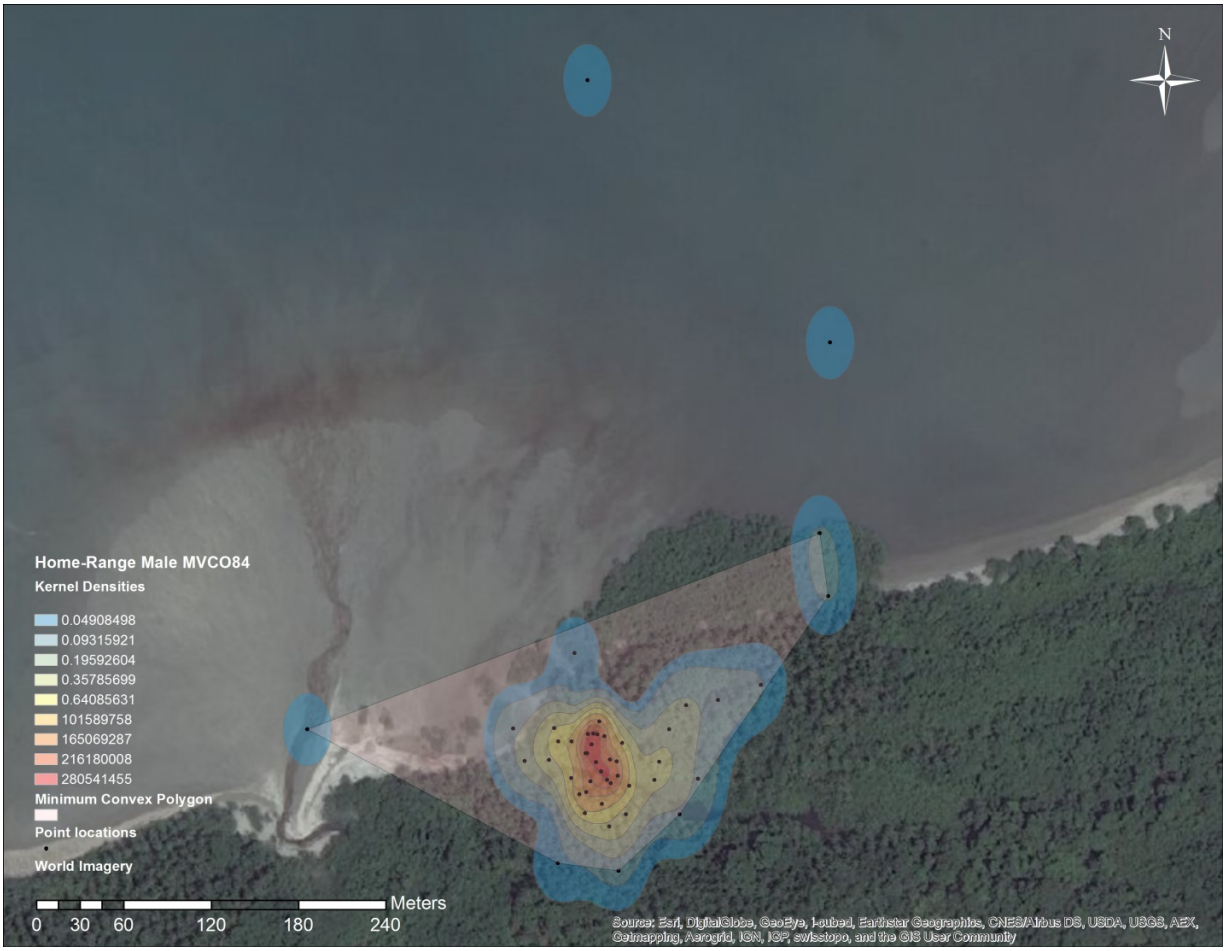



Figure 5. Home-range estimate for crocodile MVCO84. Red dots represent individual MVCO84 positions from October to December 2010. Concentric circles represent the result of Kerner analysis to calculate individual MVCO84 home-range. The center in red shows the most dense area (Area were individual spend most of his time). Triangle represent the MVCO84 Home-Range Minimum calculated using Convex Polygon analysis to function in ArcMap 10.2. Map of the area was taken from Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. This World Imagery provides one meter or better satellite and aerial imagery in many parts of the world and lower resolution satellite imagery worldwide. The map includes 15m TerraColor imagery at small and mid-scales (591M down to 72k) and 2.5m SPOT Imagery (288k to 72k) for the world, and USGS 15m Landsat imagery for Antarctica. The map features 0.3m resolution imagery in the continental United States and 0.6m resolution imagery in parts of Western Europe from Digital Globe. In other parts of the world, 1 meter resolution imagery is available from GeoEye IKONOS, i-cubed Nationwide Prime, Getmapping, AeroGRID, IGN Spain, and IGP Portugal. Additionally, imagery at different resolutions has been contributed by the GIS User Community. For more information on this map, including the terms of use, visit us <a href="http://goto.arcgisonline.com/maps/World_Imagery " target="_new" >online</a>.

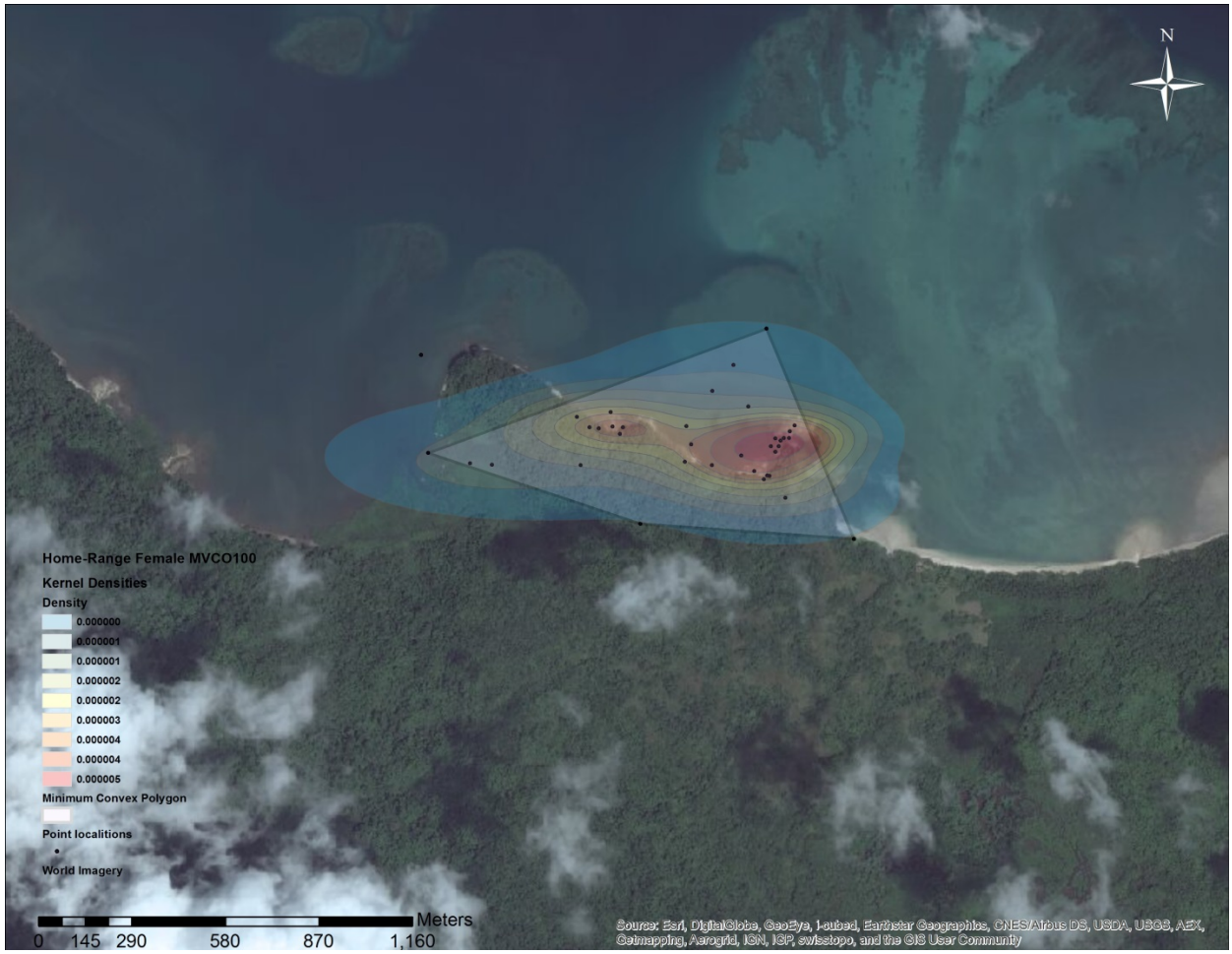



Figure 6. Home-range estimate for crocodile MVCO100. Red dots represent individual Female MVCO100 positions from October to December 2010. Concentric circles represent the result of Kernel analysis to calculate individual MVCO100 home-range. The center in red shows the most dense area (Area were individual spend most of his time). Triangle represent the MVCO100 Home-Range Minimum calculated using Convex Polygon analysis to function in ArcMap 10.2. Map of the area was taken from Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. This World Imagery provides one meter or better satellite and aerial imagery in many parts of the world and lower resolution satellite imagery worldwide. The map includes 15m TerraColor imagery at small and mid-scales (591M down to 72k) and 2.5m SPOT Imagery (288k to 72k) for the world, and USGS 15m Landsat imagery for Antarctica. The map features 0.3m resolution imagery in the continental United States and 0.6m resolution imagery in parts of Western Europe from Digital Globe. In other parts of the world, 1 meter resolution imagery is available from GeoEye IKONOS, i-cubed Nationwide Prime, Getmapping, AeroGRID, IGN Spain, and IGP Portugal. Additionally, imagery at different resolutions has been contributed by the GIS User Community. For more information on this map, including the terms of use, visit us <a href="http://goto.arcgisonline.com/maps/World_Imagery " target="_new" >online</a>.

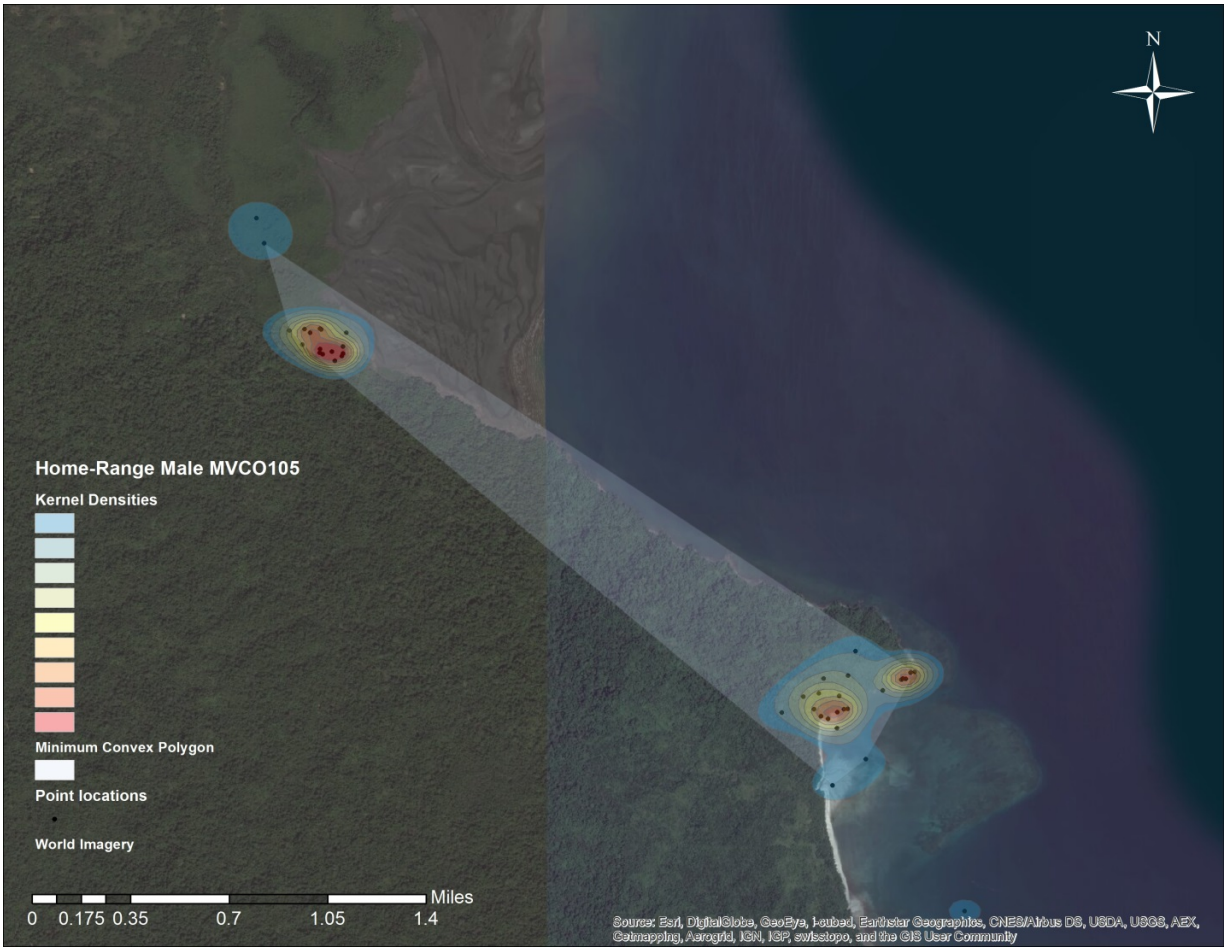



Figure 7. Home-range estimate for crocodile MVCO105. Red dots represent individual MVCO105 positions from October to December 2010. Concentric circles represent the result of Kernel analysis to calculate individual MVCO105 home-range. The center in red shows the most dense area (Area were individual spend most of his time). Triangle represent the MVCO105 Home-Range Minimum calculated using Convex Polygon analysis to function in ArcMap 10.2. Map of the area was taken from Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. This World Imagery provides one meter or better satellite and aerial imagery in many parts of the world and lower resolution satellite imagery worldwide. The map includes 15m TerraColor imagery at small and mid-scales (591M down to 72k) and 2.5m SPOT Imagery (288k to 72k) for the world, and USGS 15m Landsat imagery for Antarctica. The map features 0.3m resolution imagery in the continental United States and 0.6m resolution imagery in parts of Western Europe from Digital Globe. In other parts of the world, 1 meter resolution imagery is available from GeoEye IKONOS, i-cubed Nationwide Prime, Getmapping, AeroGRID, IGN Spain, and IGP Portugal. Additionally, imagery at different resolutions has been contributed by the GIS User Community. For more information on this map, including the terms of use, visit us <a href="http://goto.arcgisonline.com/maps/World_Imagery " target="_new" >online</a>.




Figure 8. Summary of home-ranges for all American crocodiles sampled. It is showing all locations and the Minimum Convex Polygon Home-Range for individual MVCO82 (light yellow dots), MVCO84 (dark blue dots), Female MVCO100 (purple dots) and MVCO105 (dark green dots), collected from October to December 2010 from Punta Felipa to Boca Grande, Southwest of Coiba Island, Panama.

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**Note: Tables 1-4 can be obtained by contacting Dr. Miryam Venegas-Anaya.**