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SPATIAL VARIABILITY OF NILE CROCODILES (*CROCODYLUS NILOTICUS*) IN THE LOWER ZAMBEZI RIVER REACHES

VINCENT R. NYIRENDA

Department of Zoology and Aquatic Sciences, School of Natural Resources, The Copperbelt University, Kitwe, Zambia, e-mail: vrnyirenda@hotmail.com

***Abstract*.—I compared four areas under different protection regimes to ascertain the status of Nile Crocodiles (*Crocodylus niloticus,* Laurenti 1768) in the Lower Zambezi River reaches. I used a night spotlighting survey, conducted to sight Nile Crocodiles within the distance of ≤ 5 m to river banks, to establish indicators of crocodilian encounter rates and body size classes. I employed Global Positioning System (GPS) to determine spatial locations of sighted crocodiles and I categorized the size class of crocodiles I saw visually. High encounter rates coincided with high protection status along the river reaches and vise versa. The mean Nile Crocodile count for reaches with national parks flanks was 20.62 ± 0.44 (± SE) crocodiles/km river stretch while the overall mean for non-protected areas was 7.45 ± 0.76 (± SE) crocodiles/km river stretch. Further studies on impacts of protection regimes on persistence of crocodilians are needed. Although I studied crocodiles at a local regional scale, this study has applications and relevance to various protected areas management settings and species for biodiversity conservation.**

Key Words.—Africa; conservation status; night spotlighting; population indices

INTRODUCTION

The aspects of life history of Nile Crocodiles (*Crocodylus niloticus*, Laurenti 1768) have been described by several researchers including Craig (1992), Aust (2009), and Chomba et al. (2014). These researchers relate that Nile Crocodiles are sexually dimorphic and apex predators, capable of consuming a wide array of prey and are distributed in much of the sub-Saharan Africa. A female Nile Crocodile produces clutch sizes of between 20 and 60 eggs in a nest during the nesting period that lasts largely between September and March. Nile Crocodiles are considered a keystone species that regulate the wetland ecosystem wherever they exist (Roff and Zacharias 2001). They are capable of creating sanctuary areas for other species such as fish in the burrowed banks of the river and also create watering points for the ungulates (Alderton 1991). In the Zambezi River, ungulates concentrate at and use such watering points, particularly in the dry season. Nile Crocodiles also contribute to local economies through production of hides (Khosa et al. 2011; Chomba et al. 2014). Despite these ecological and economic contributions at local and international scales, Nile Crocodiles are considered vulnerable, requiring management action (IUCN 2014) by conserving genetic variation and habitat to avoid species extinction (Hardes and Spellerberg 1992; Sinclair et al. 2006).

In the 1980s and 1990s, Nile Crocodiles were widely spread and abundant along the entire stretch of the Zambezi River (Department of National Parks and Wildlife Services 1993). In recent years, however, there has been growing evidence of declining Nile crocodiles in eastern and southern Africa (Botha et al. 2011; Combrink et al. 2011) and Zambia in particular (Chomba et al. 2014). In human dominated landscapes, the risk of extirpation of Nile crocodiles is greater due to numerous human-crocodile conflicts associated with degradation of human livelihoods by crocodilians (Aust 2009). For instance, there is increasing competition between humans and crocodilians for space and fish resources in riparian environments, upon which both the rural populace and crocodilians need to survive (Lamarque et al. 2009). The reasons for the decline of the Nile Crocodile populations include reduced effective population sizes due to overexploitation (Bishop et al. 2009), habitat destruction by anthropogenic activities such as overfishing and disturbances to nesting sites, environmental factors like flooding, high temperatures that increase crocodile mortalities (Chomba et al. 2014), and high rates of predation (Ross and Garnet 1990).

Indices as estimators of species abundance, richness, and diversity are useful in comparative population studies (Lancia et al. 1996). Nevertheless, the impact of the level of protection on crocodilians has rarely been explored in relation to such indices. The focus of this study is the impact on the persistence of Nile Crocodiles by the status of habitat protection along sectional reaches of the Zambezi River. The status of habitat protection refers to whether the crocodile habitat occurred adjacent to a national park (with strict or high protection from wildlife agencies), or game management area and safari area (with moderate protection), or was an open area (with low protection). Consequently, I hypothesize that

FIGURE 1. Nile Crocodiles (*Crocodylus niloticus*) along the Zambezi River, Zambia, in 2007. (Photographed by Vincent R. Nyirenda).

habitat protection status influences the Nile Crocodiles persistence along the Lower Zambezi reaches.

MATERIALS AND METHODS

***Study site*.—**I surveyed the Nile Crocodiles (Fig. 1.) on a Zambezi River stretch from Siavonga at Namoonga-Hurungwe, north of Lake Kariba to Feira, Zambia, in October 2007 (Fig. 2). The study area, the Lower Zambezi River section, forms river frontage for different protected area systems on its flanks over a river distance of 262 km (Fig. 2). The Zambezi River occurs in southern Africa and also serves as the country boundary between Zambia and Zimbabwe. It marks the southern boundary of the Lower Zambezi National Park (NP), the Chiawa and Rufunsa Game Management Areas (GMAs), and the Siavonga Open Areas (OA) on the Zambian side. On the Zimbabwean side, it is the northern portion of the country and constitutes Mana Pools NP, the Sapi Safari Area (SA), the Chewore SA, the Hurungwe SA, and the Dande Communal land. I subdivided the river stretch into four segments: Rufunsa GMA-Chewore SA-Dande Communal land (Segment A), Lower Zambezi NP-Mana Pools NP-Sapi SA-Chewore SA (Segment B), Chiawa GMA-Mana Pools NP-Hurungwe SA (Segment C), and Siavonga OA-Hurungwe SA (Segment D; Fig. 2). Portions of the Zambezi River are on wide, up to 50 m, with several islands and sand bars, located in a narrow band of floodplains flanked by the escarpments. The predominant riparian vegetation types along the Zambezi River are *Phragmites mauritianus, Colophospermum mopane, Kigeria africana, Acacia* spp., and *Diospirus kirki*.

According to the Zambia Wildlife Authority (unpubl. report), the Lower Zambezi ecosystem experiences three climatic seasons: hot rainy season (late November to March), cool dry season (May to August), and hot dry season (September to early November). During October in the hot, dry season when I conducted the survey, the temperature averaged 30° C in the day and the nights were cool. Mean annual rainfall in the Lower Zambezi valley is about 740 mm, with precipitation peak between December and March, and little rain falls during October. October coincides with a period when the Nile Crocodiles are also laying eggs. Due to reduced precipitation and high surface evaporation rates, the river channel contains low volumes of water. The water level is low and in some river portions, the river cuts and exposes the sand beds.

The Lower Zambezi aquatic system hosts various land use types *inter alia*: commercial and traditional fishing, tourism, and transportation. Due to these anthropogenic practices, the river frontage is relatively heavily settled, particularly on the Zambian side in Rufunsa, Chiawa, and Siavonga areas. Both Zambia and Zimbabwe approximate and follow the proposed IUCN (1994) protected areas categorization, with their corresponding levels of protection. National parks have higher protection levels than the other conservation areas in the study area, though the safari areas in Zimbabwe are sparsely settled. The establishment and conservation regimes of national parks have a legacy of evictions of local communities from parks, mostly between 1960s–1980s, which continue to pose conservation antagonism between wildlife agencies and local communities (Mwima 2001; Child 2009). Poor relationships still exist where community based conservation initiatives remain ineffective.

In southern Africa, Stevenson-Hamilton popularized the concept of national parks establishment to protect diversity Hotspots in selected wildlife reserves (Carruthers 1995). Starting with preservationist notions, sustainable use of natural resources in parks gained ground thereafter (Riney 1967; Child 2009). However, the centralist and non-commercial political economic philosophy set out in the London Convention in 1933, which many of the wildlife agencies adopted, tends to skew and concentrate technical and financial support to biodiversity conservation in national parks at the expense of other areas. These parks also host high biodiversity, including crocodiles. For example, the Lower Zambezi NP, under category II of IUCN protected areas categorization, has 75.27 km^2/scout protection levels. The natural resource exploitation is limited to ecotourism to safeguard its ecosystem integrity, though at the beginning of the 2000s, the park was put to limited extractive use of minerals. Rufunsa and Chiawa GMAs, which are in IUCN category VI of protected areas systems straddle on the north-eastern and

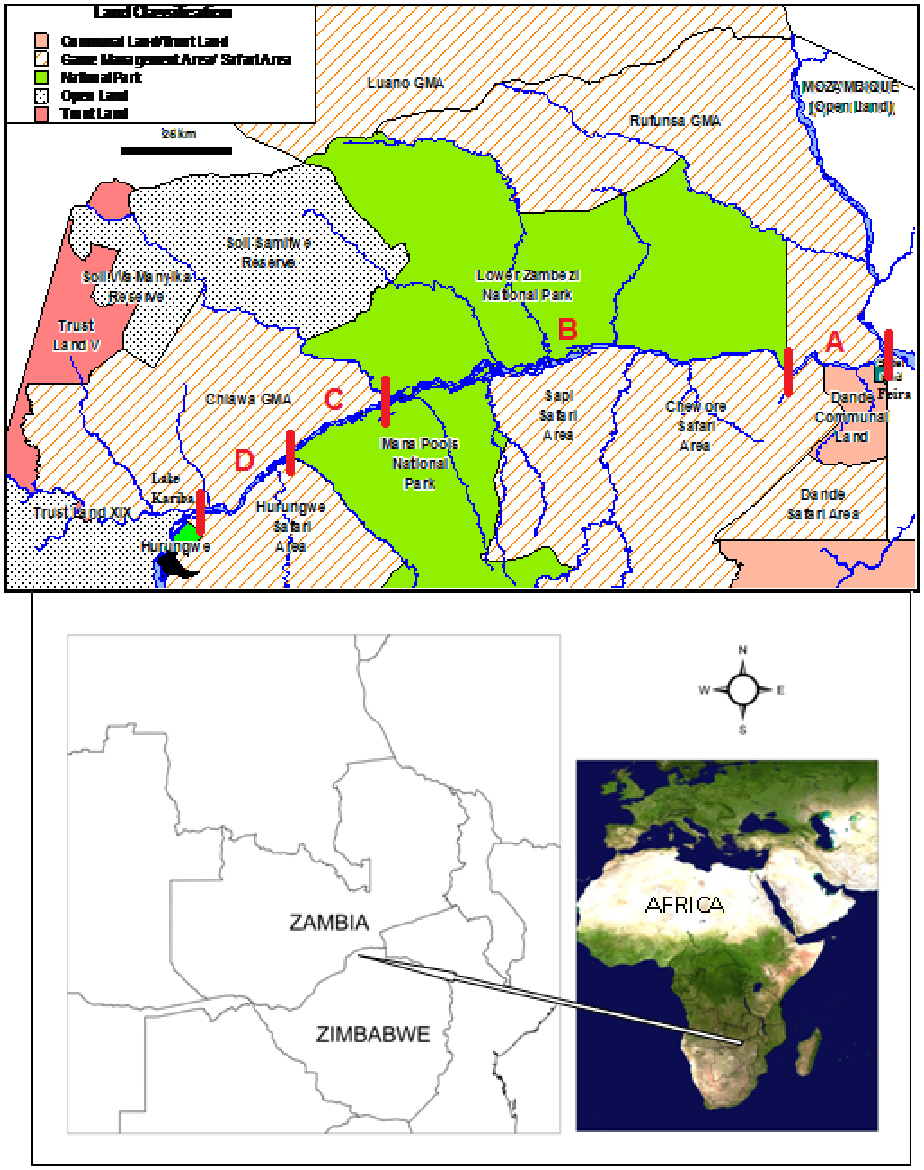

FIGURE 2. Study area (below) showing stretches of the Zambezi River (red letters; above) on the boundary between Zambia and Zimbabwe where counts were made of Nile Crocodiles (*Crocodylus niloticus*) in 2007.

south-western parts of Lower Zambezi NP, where the protection indices stand at 123.37 km^2/scout and 122.27 km^2/scout protection levels, respectively. In these areas, multiple and legal natural resource uses like sustainable consumptive (e.g., hunting and egg collection) and non-consumptive (e.g., photographic) safaris are permitted, though similar but illegal natural resource uses are also common. Siavonga OA receives the least of the protection with more than 200 km^2 /scout protection levels, while natural resource uses are largely uncontrolled.

***Data collection protocols*.—**I used spotlighting methods for night counts of crocodiles (Bayliss 1987; Hutton and Woolhouse 1989; Games 1994; Brown et al. 2005). I used 12-volt battery powered lighting system projected ≤ 5 m towards the river banks, where Nile Crocodiles congregate. The sighting distance varied with depth of the river for navigation purposes as at the time of the survey the water levels were generally low. The reflective nature of the *tapetum lucidum* (a layer of tissue in the eyes that reflects visible light) results in eyes reflecting red light once illuminated and made the detection of the Nile Crocodiles possible. For maximum detection, I placed the spotlight just below eye-level and rotated the spotlight at an angle between 0° and 45° in the direction of the boat movement. I applied correction factors under selected environmental factors of temperatures and water depths as outlined by Bourquin and Leslie (2011) because Nile Crocodiles are ectothermic animals that continuously respond to changes in ambient temperatures and surrounding environments. Preceding the crocodile counts, I conducted repeated night spotlight counts under various conditions of temperature (hot, warm, and cold) and water depths (narrow and deep) of various river sections. At the time of survey, the cloud cover was near zero. Due to a long and expansive study area, I applied the resultant data from the correction factors to data analyses across the entire survey area. However, the night spotlighting survey method over the survey area posed challenges such as high risks associated with navigations on the Zambezi River, which has several rapids, deviating channels, and shallow waters, particularly during the drier months of September and November. I assumed that the observer biases were mechanically corrected due to combined effort of search by the consistent survey team of three on each of the two survey tandem boats as every member was actively involved in sighting crocodiles along the spotlighting swath.

Pre-determined body size classes of the Nile Crocodiles formed the basis for identification of crocodiles at each sighting site (Table 1). The categories did not include Class 1, which represents hatchlings, because there were no hatchlings at the time of the survey as the young of the year had already grown beyond the hatchling size class. I could not determine the actual age of the Nile Crocodiles sighted in the field because there were no reliable methods conducted for age determination in wild crocodiles. Instead, I used indices to assign crocodiles to age categories (Table 1).

Each survey team was composed of a trained and experienced navigator, recorder, and observer. Each person previously had been involved in estimating sizes, capturing crocodiles to validate estimates, and releasing them into their original habitats. All team members participated in the detection of crocodiles and once we made a sighting, we navigated closer to each Nile Crocodile where an observer made further observations to determine and allot the crocodile to a particular body size category. In this case, we reduced the navigation speed to allow for accurate estimation and also avoid rapid concealment of the sighted target.

Table 1. Nile Crocodile (*Crocodylus niloticus*) size classes and their description in the Lower Zambezi River reaches on the boundary between Zambia and Zimbabwe.

Classes	Description
Class 1	< 0.5 m of body length.
Class 2	Juveniles 0.5–1.0 m body length.
Class 3	Sub-adults with body length 1.0–2.5 m.
Class 4	Adults > 2.5 m of body length.
Eyes Only	Presence detected by eye-shine; body length undetermined.

We started the survey of each section of the segment at 1900 and ended at the completion of the survey session, about 3 h later. We did not extend the survey times to avoid exhausting survey team members, which can affect their ability to sight crocodiles. To navigate, we used two GPS sets (Garmin 72, Garmin International, Inc., Olathe, Kansas, USA) using the WGS 1984 coordinate system and base maps with distance grids. We measured the river length in a straight line as opposed to following the bends of the river.

***Data analyses*.—**I used Minitab, version 14 (Minitab Inc., Pennsylvania, USA) statistical software for analyses. I established lower and upper limits of indices of relative abundance of Nile Crocodiles in each segment using correction factors: number seen × 1.70 and number seen × 3.00, respectively. These correction factors are the mean counts of Nile Crocodiles from the sightings made at selected river stretches at different relative ambient temperatures and water depths. Because not all Nile Crocodiles in a stretch could be seen during each survey and because the entire study area was surveyed only once (except for selected sections where I derived correction factors), I calculated the mean lowest and highest numbers in such repeated surveys. I then applied these correction factors to the entire study area that was surveyed once as described by Bourquin and Leslie (2011). In this way, I avoided surveying each stretch repeatedly under changing environmental conditions. Therefore, I established lower and upper limits of the population indices based on mean lowest and highest numbers of crocodiles sighted in repeated counts under various prevailing environmental conditions in 20 selected portions of 1-km river stretches. Though counts can be corrected for visibility bias by estimating sighting proportions to estimate population size, sighting proportion may vary depending on seasons, habitat type, and environmental conditions like moon phase, water temperature, and depth (Da Silveira et al. 2008; Woodward et al. 1996). Each segment of the survey was conducted under similar conditions and accordingly, I applied the correction factors to similar settings. Further, I adopted use of relative abundances to determine comparable populations across the study stretch (Sinclair et al. 2006).

I transformed the crocodile count data using natural logarithms to correct for normality (Fowler et al. 2006)

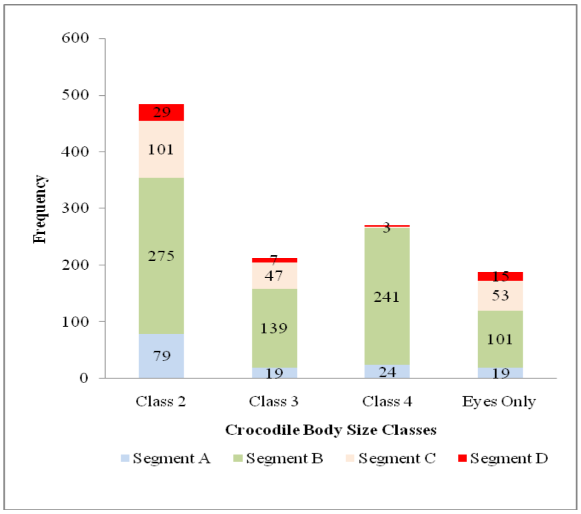

FIGURE 3. Actual sightings per size class of Nile Crocodiles (*Crocodylus niloticus*) in the Lower Zambezi reaches on the boundary between Zambia and Zimbabwe, 2007.

and then I applied a one-way Analysis of Variance (ANOVA) to examine the relationship between crocodile sample counts in the various segments of the Lower Zambezi River reaches ($\alpha = 0.05$). Further, I divided each segment into 5 km sub-segments at a resolution of ≥ 5 km stretch to avoid spatial autocorrelation (Koenig 1999). This minimized the possibility of committing a Type I error (Reilly and Reilly 2003). The enumeration of Nile Crocodiles over sub-segments added detail to comparisons between segments.

RESULTS

Population indices.—I estimated 1,152 Nile Crocodiles in classes 2−4 in the entire study area (Fig. 3); 484 Nile Crocodiles sighted in class 2; 212 in class 3; and 268 in class 4. Further, I estimated 188 Nile Crocodiles as Eyes Only or as unclassified crocodiles. The distribution of mean corrected numbers of Nile Crocodiles (with standard errors) varied across partitioned segments of the Lower Zambezi River reaches, with their corrected lower and upper indices (Fig. 4). The total corrected Nile Crocodile population indices in the Lower Zambezi ranged from 1,961 to 3,460 crocodiles. These were population indices of relative abundances expressed from minimum alive crocodiles estimates and not population estimates, which would need detection probabilities and repeated observations across seasons. Further, in population estimates, large confidence intervals would be precursor of small sample sizes (Fowler et al. 2006).

Intensity of occurrence and geo-spatial distribution of crocodiles.—The search rates (mean ± SE) ranged from 11.76 ± 0.87 km/h to 13.99 ± 0.42 km/h. Counts of Nile Crocodiles differed significantly across the sections under different protection regimes ($F_{3,50} = 179.58$, $P = 0.001$), except for Segments A and C. Segment A had a mean count of 52.50 ± 5.17 crocodiles (range: 27−79), Segment B had a mean count of 103.09 ± 2.18 crocodiles (range: 90−134), Segment C had a mean count of 51.00 ± 3.93 crocodiles (range: 21−63) and Segment D had a mean count of 13.33 ± 0.92 crocodiles (range: 6–17). The highest concentrations of crocodiles were on the stretch of the Lower Zambezi NP-Mana Pools NP-Sapi SA-Chewore SA, especially at the edges of and along the Mphata Gorges on the south-eastern portion of Lower Zambezi NP (Fig. 5). In reaches adjacent to Mphata gorge, south east of Lower Zambezi NP, there were 25 Nile Crocodiles at a single site, which was a rare sighting. The mean count of Nile Crocodiles for reaches at the edge of national parks was 20.62 ± 0.44 crocodiles/km river stretch while the overall mean for non-protected areas was 7.45 ± 0.76 crocodiles/km river stretch. Siavonga OA-Hurungwe SA and south-western part of the Chiawa GMA stretches had the lowest concentrations of 2.77 ± 0.18 crocodiles/km river stretch. The rest of the study area had moderate concentrations of Nile Crocodiles.

DISCUSSION

High human use restriction of water resources in national parks sections enhanced the status of the Nile Crocodile. In contrast, in areas where limited habitat protection was enforced, particularly the Siavonga OA, the population status was relatively less abundant during the sample period, recognizing that relative abundance is subject to seasonal and annual variations, which were outside the scope of this study. The traditional threats to crocodilian species are documented and include opportunistic retribution killing, trapping by fish nets, habitat destruction, and overharvesting of eggs (Platt and Thorbjarnarson 2000; Kampamba et al. 2005; Lamarque et al. 2009). Crocodile populations in the wild in the Lower Zambezi area are threatened by such anthropogenic activities. However, the support from the crocodile farming industry would enhance persistence of Nile Crocodiles (Chomba et al. 2014). Further, insights from conservation in practice have shown that innovative measures that benefit local communities such as primary crocodile producers (farms) trigger effective community participation in crocodilian conservation (Thorbjarnarson 1999; McGregor 2005).

Crocodile conservation has numerous advantages emanating from legal use of crocodilian products, but the viability of such products links to how sustainable wild populations may be. Therefore, innovative conservation measures that would benefit local communities, sharing crocodile habitats and bearing the costs of living with

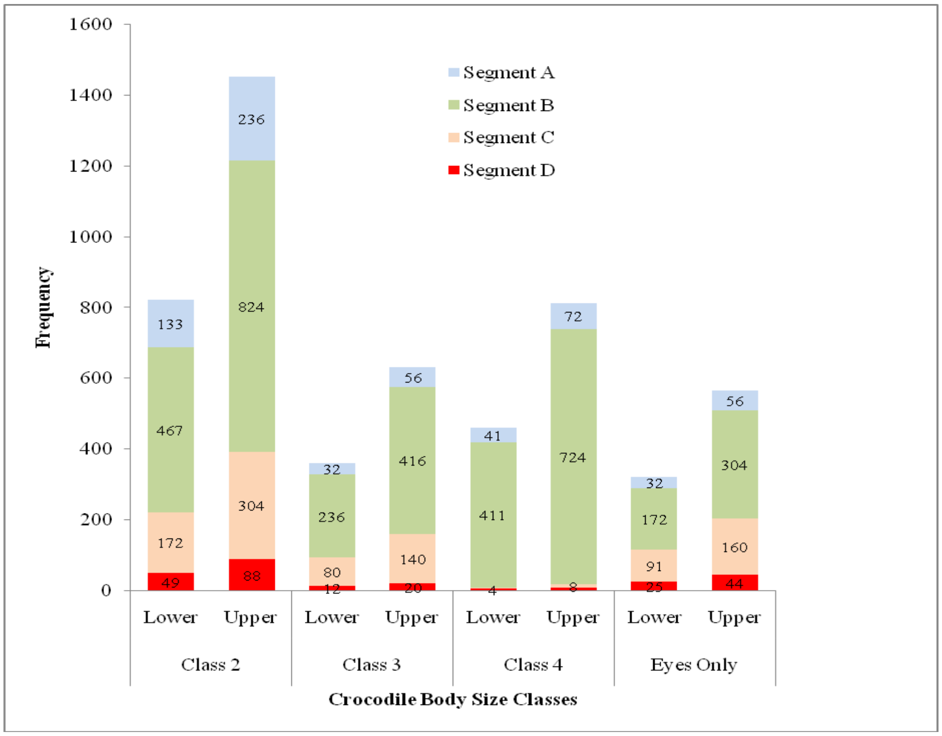

FIGURE 4. Corrected lower and upper indices for Nile Crocodiles (*Crocodylus niloticus*) across the four segments between Siavonga and Feira in the Lower Zambezi River reaches, on the boundary between Zambia and Zimbabwe, 2007.

crocodiles, such as primary crocodile producers in communal areas, should be designed and implemented. Involvement of local communities in wildlife conservation could be one cost-effective strategy to crocodile conservation with consummate benefits (Thorbjarnarson 1999; McGregor 2005; Child 2009).

In Zambia, Nile Crocodiles have damaged fish nets and caused occasional bodily injuries and deaths to humans. These impacts have resulted in resentment among local communities and consequently, retribution killing of crocodiles in the study area (Wallace et al. 2011). Such human-crocodile conflicts are a great threat to the persistence of Nile Crocodile populations (Brooks et al. 1995; Aust et al. 2009; Lamarque et al. 2009). Deliberate and targeted interventions like sensitization and awareness campaigns therefore have to be innovatively intensified to conserve Nile Crocodiles. However, one limiting factor to biological conservation is the perceived high costs of conservation efforts. Due to this perception, wildlife agencies have most often focused their operations to core areas such as national parks and reserves, leaving other wildlife habitats susceptible to species depletion. Spatial distributions of biological benefits and economic costs could, however, culminate into substantially large biological gains with limited budgets through conservation planning (Balmford et al. 2006; Naidoo et al. 2006). Even with relatively little financial resources in place, concerted efforts to conserve flagship and protected species such as Nile Crocodiles regardless of where they occur is viable and imperative. Nile Crocodiles act as flagship species due to their being a popular, charismatic species that serves as a symbol and target species to stimulate conservation awareness and action (Heywood 1995). Continued monitoring and research of crocodilian populations is recommended to determine crocodilian population patterns and status, and their use of different aquatic habitats. Therefore, development and implementation of a detailed long term monitoring framework would play a major role in crocodile conservation. Such a framework would facilitate addressing anthropogenic and ecological factors in a spatial context.

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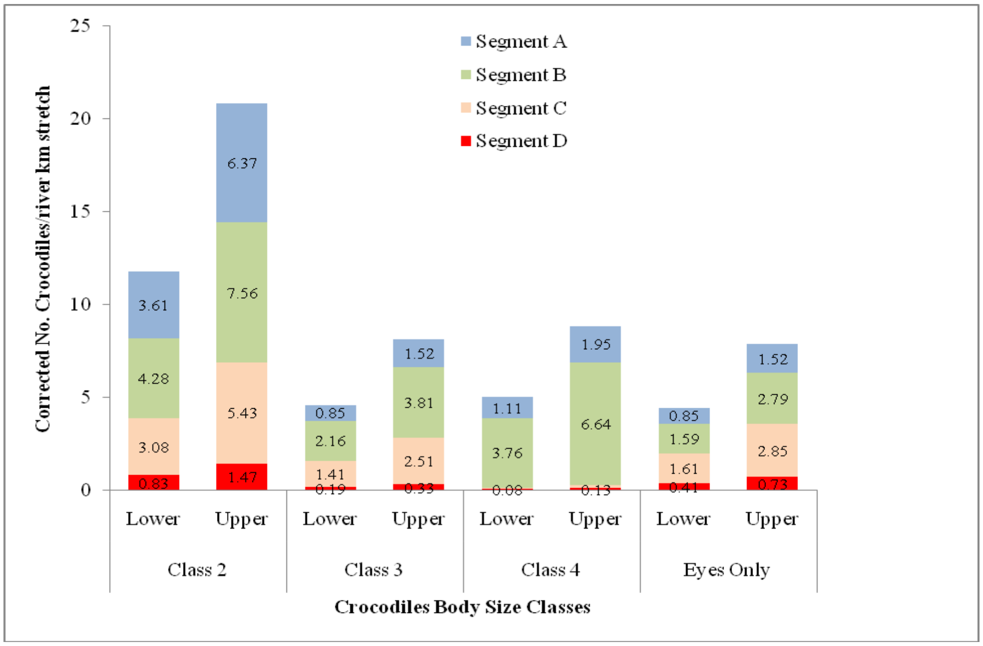

FIGURE 5. Encounter rates (corrected number of crocodiles/river km stretch) of Nile Crocodiles (*Crocodylus niloticus*) per class in segments of Lower Zambezi River reaches, on the boundary between Zambia and Zimbabwe, 2007.

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VINCENT R. NYIRENDA (B.Sc., M.Sc., Ph.D.) has over 20 y of experience in wildlife management as a Wildlife Biologist, with professional experience at local, regional, and international levels. He has held senior portfolios in wildlife and environment sectors in government, international organizations, and academia. Currently, he is a Senior Lecturer in the Department of Zoology and Aquatic Sciences in the School of Natural Resources at The Copperbelt University, Kitwe, Zambia. At regional and international levels, he has contributed to Southern African Development Community (SADC), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Convention on Conservation of Migratory Species of Wild Animals (CMS), African-Eurasian Migratory Waterbird Agreement (AEWA), Southern African Sustainable Use Specialist Group (SASUSG) and Crocodile Specialist Group of the International Union for Conservation of Nature (IUCN). He has authored and co-authored over 35 peer-reviewed journal articles. (Photographed by Charles Matipa).