Factors affecting lakeshore use of Muggers (*Crocodylus palustris*) in Vihar Lake, Sanjay Gandhi National Park, Mumbai, India



Submitted to

IUCN-SSC Crocodile Specialist Group

by

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Introduction

The Marsh Crocodile or Mugger (*Crocodylus palustris*) is one of the three species of crocodilians in India. The Mugger has a wide distributional range (Whitaker, 1987). Muggers are moderately-sized (average body length = 3 ± 1 m) crocodilians, and can live in both natural and artificially-created freshwater bodies (Whitaker and Whitaker, 1989). Muggers were widespread in India until the 1950's when the demand for their hide almost wiped out the species from many parts of the country (Whitaker 1987). Post India's Independence, in the 1950's, the fisheries department in India offered Rs. 50 (*c.* $0.8) to kill a crocodile and Rs. 10 (*c.* $0.2) to destroy an egg at Powai Lake in Mumbai (then Bombay) (Whitaker and Andrews, 2003). Throughout India, Mugger numbers further declined over the next three decades due to the loss of habitat and destruction or modification of banks of waterbodies (Bustard, 1981). Illegal collection of eggs, demand for crocodile skin and meat, and drowning in fish nets proved to be additional causes for their decline during this time (Britton, 1995; Whitaker 1987).

In 1975, the UNDP/FAO Crocodile Breeding and Management Program was initiated with the help of the Government of India (De Vos, 1984). Sixteen specialised rehabilitation centres were established in a few states across the country. A total of 1193 Mugger crocodiles were introduced in 28 national parks, wildlife sanctuaries and protected areas between 1978 and 1992 across these Indian states to increase their wild populations in the country (Choudhury and Choudhury, 1986).

Current population size estimates of wild Muggers range from 5700-8700 across their range, and about 3021-4287 in India (Whitaker and Andrews, 2003; Choudhury and de Silva, 2013). The species is categorized as Vulnerable, as the overall population appears to be stable or increasing in many parts in India, even in densely populated suburban regions (Vyas, 2012; Choudhury and de Silva, 2013). Increase in Mugger population size is linked to increase in human-crocodile conflict (Whitaker, 2007; Whitaker, 2008); however scientific monitoring of restocked Mugger populations and Mugger habitat use is inadequate in India to frame adequate mitigation measures and management plans (Da Silva and Lenin, 2010).

We studied a Mugger population in a lentic environment in a densely-populated (human population density of 20,980/km^2 (http://mumbaisuburban.gov.in/html/indexenglish.htm) environment in suburban Mumbai to understand habitat (lakeshore) usage of an introduced population. The Vihar lake, neighbouring the southern edge of Sanjay Gandhi National Park, in suburban Mumbai is known to harbour Mugger crocodiles. Muggers and humans often share space along the lakeshore, yet there is limited understanding of whether and how human activity affects Mugger use of lakeshore habitat. Human activities such a fishing, both by tribals, local residents, and migrants (Parthasarthy, 2011) in the lake, and washing of clothes, utensils and vehicles, bathing, and cattle grazing, were observed to occur extensively along the lake-shore during the day-time, creating potentially conflicting circumstances. One fatal attack on a man has been recorded from Vihar lake in 2010, necessitating better understanding of how ecological factors and human activity influence Mugger use of habitat along a lakeshore in a densely-populated suburban environment.

The aim of this study was to assess ecological and anthropogenic determinants of lakeshore use by Muggers in a suburban lake environment, to enable better management for human-crocodile coexistence. No population counts are available for crocodiles in Vihar Lake, and in the absence of radio-tagged individuals, we used sign surveys in an occupancy modelling framework to understand lakeshore use by Muggers, so as to deal with imperfect detections in observational

studies (Mackenzie, 2002; Mazerolle *et al*., 2007). Such studies are cost-effective, and can be potentially useful in surveying lake environments to assess crocodile preferences and designing better mitigation measures in pre-empting conflict situations.

Materials and Methods

Study Area

Vihar Lake (19.1440^{o} N and 72.910^{o} E) is considered to be the largest lake in the Greater Mumbai region. It is located at the southern edge of Sanjay Gandhi National Park and thus human activity in and around the northern periphery of the lake is considerably reduced. The lake supplies about 3% of the city's water requirements. A large water filtration plant is located at Bhandup, near the lake and this filters the water before being supplied to the city (http://theory.tifr.res.in/bombay/history/water.html). The lake has a maximum depth of 34 m. The total water spread are of the lake is about 7.26 km^{2}.

Vihar Lake offered a useful model environment to assess lakeshore use of Muggers given that it is bordering a National Park, thus we expected a gradient of human activity along the lakeshore. Part of the lake falls under the jurisdiction of the Sanjay Gandhi National Park, while much of it falls under the jurisdiction of the Brihanmumbai Municipal Corporation. Shoreline areas within the park were expected to have lower human activity as opposed to those outside the National Park limits.

The region experiences much variation is weather and precipitation across seasons: Winter (December-February), Summer (March-May), Monsoon (June-September), Post-monsoon (October-December). Most precipitation is received during the Monsoon season.

Field methods

As the lake has a perimeter of 15.5 km, we divided the lakeshore into 31 segments (sampling units), with each segment being 500 m in length and 30 m width on either side, centred on the lake shoreline. This measure has been taken after considering the ecology, and site fidelity of the target species (Whitaker and Whitaker, 1989). This unit of 500 m x 60 m is estimated to be big enough for an individual crocodile to use. Although Muggers will use areas in the lake, beyond the lake shore and our sampling unit, as we could not physically sample the portions in the deep waters we restricted our interpretations to this region of the lake shore.

We divided the lake into 31 segments (sampling unit) of 500 m x 60 m each. Each 500 m x 60 m sampling unit was further sub-divided into 5 spatial replicates of 100 m x 60 m length and width. One team, comprising of two to five people, sampled each sampling unit, by surveying five spatial replicates in each unit. Thus, in this manner, each sampling unit had five occasions in the capture history.

In the winter season, we surveyed 13 sampling units on day one, 10 on day 2 and 8 on day three. All sightings and indirect signs were recorded using a hand-held GARMIN e-trex 30 GPS (Garmin Inc., USA).

In the summer season (month of Apri) l, we used temporal replication to sample the lake. Each 100 m x 60 m segment was surveyed by one observer, independently of each other. This way a

total of 155 segments were surveyed by the survey team. A total of seven observers walked each segment recording data. 5 observers recorded presence absence data while two observers measured covariates, which included water depth, visual cover and slope. Two days were required for completing the entire survey. We completed 15 segments on day one and 16 segments on day two. Five observers walked the segments looking for indirect signs and two observers would record covariates.

Presence of indirect signs like burrows, tracks, and scat were identified by trained observers and direct sightings were also recorded. In case of direct sightings, a Binocular (Celestron – outland X 10x42) was used to confirm the direct sighting before being recorded. However a presence was only recorded for the replicate if the individual crocodile was found at the lakeshore. Sightings beyond 30 m from the lakeshore were only recorded but not used in the analysis of Mugger lakeshore use.

From literature surveys and our understanding of the Mugger ecology, we measured ecological correlates that may potentially affect lakeshore use of crocodiles (Somaweera *et al*., 2011). These included visual obstruction from the lakeshore, water depth at the lakeshore, slope of the lakeshore, canopy cover, presence of floating vegetation, percentage ground cover, and type of substrate.

We measured visual obstruction using a Robel pole (Robel, 1970; Smith, 2008). The Robel pole had 50 bands, with each band measuring two cm. The bands were alternately coloured white and black to facilitate easy spotting within the vegetation (Smith, 2008). Visual obstruction was measured (in cm) from the centre of every 100 m spatial replicate using the pole at a height of 1 m above the ground at a distance of 8 m away in three cardinal directions. The fourth direction was inaccessible as it faced the lake having high water depth. A distance of 8 m was assumed to be a satisfactory considering visual obstruction and the height of a crocodile.

Slope of the lakeshore in each replicate was recorded using a clinometer in degrees. The instrument was kept on the surface near the lakeshore and slope of each replicate was recorded. Mean slope was calculated for every 500 m x 60 m sampling unit. Canopy cover was measured by taking a photograph of the canopy overhead at the start, centre, and end of each 100 m x 60 m spatial replicate (Evans and Coombe, 1959), if canopy was present, otherwise it was recorded as zero. Canopy cover was estimated by visually calculating the total area the canopy occupied in each photograph as a percentage. This was averaged across the entire sampling unit.

We recorded floating vegetation as presence/absence, with 1 indicating presence of floating vegetation in every 100 m spatial replicate and 0 indicating absence.

We classified ground cover into two categories in every 100 m spatial replicate. Presence of grass, reed and shrub/tree were considered as “presence of ground cover” and was entered as 1, while bare ground was considered to be “absence of ground cover” and was entered as 0. For every 500 m sampling unit, ground cover was then calculated as proportional cover. For example, if ground cover for a sampling unit was 10110, then the percentage of ground cover was given as 0.6. Substrate was recorded as a categorical variable and split into three categories- Rocky, Stone, Gravel-Clay. “Stone” represents embankments in the lake, while a rock and boulder substrate was classified as “rocky”. If “rocky” was found to be the dominant type of substrate in a segment, it would be marked as 1, and the other substrate types would be marked 0 for each 100m replicate.

We also assessed the impact of human activity on Mugger lakeshore use by recording the covariate at every 100 m spatial replicate. Human activity was recorded as present if we found evidence of fishing, washing, cooking, or bathing along the lakeshore, where 1 indicated presence and 0 indicated absence of human activity in every 100 m replicate. The total number of positive replicates in a segment made up the degree of Human activity in a segment, where 1 indicated low human presence and 5 indicated high presence.

We used the Single-Season occupancy model in software PRESENCE, Version 9.7 (Royle and Nichols, 2003) to determine lakeshore use of Muggers in two seasons. We initially conducted pair-wise correlations (Pearson's) for the covariates, and covariates with high correlations were not used together in the same model. A total of 11 *a priori* models were used in the winter season and eight *a priori* models in the summer season. Continuous variables were standardized. Models were ranked using Akaike's Information Criterion (AIC) and models which gathered 90% of the Akaike weights were considered top models. Inferences about the influence of covariates were drawn by examining the direction and effect of Beta Coefficients and associated standard errors.

Results

For the month of April (Summer season), covariates such as Human activity, Floating vegetation, and canopy cover were completely uniform, i.e. Human activity was present all throughout the lakeshore area while floating vegetation and canopy cover was completely absent. This was not the case during our visit in February (winter season). Human activity, and floating vegetation were patchy and canopy cover was present around the lake as the water spread area was more compared to the dry season. Therefore, certain lake attributes expected to affect crocodile lakeshore use are absent in particular seasons and their effect on lakeshore use would also be expected to diminish.

We ran a total of 11 *a priori* models for the winter season and 8 *a priori* models for the summer season. There was no single model that was able to explain the extent of lakeshore use by the crocodiles. Out of the 11 models that were run for the winter season, the top 6 models (ΔAIC <3) explained lakeshore use. Covariates such as, "ground cover", "visual cover", "floating vegetation", and "gravel-clay" had a slight positive influence on occupancy, while "rock" had a strong influence on detectability. The model with all the covariates mentioned earlier was ranked as the strongest in predicting lakeshore use in the winter season.

For the summer season, all the 8 models were shown to explain lakeshore use; however the models ranked lower had very low confidence, in the form of high standard error. The model "psi(slope+ visual cover),p(ground cover)" was ranked as the strongest in predicting lakeshore in the summers use based on goodness of fit.

Discussions

Because of the difficulty in conducting a population count of Muggers in the lake, we were unable to determine the number of crocodiles that were present. However, we have observed at least 11 different individuals based on time and area of sighting. The need to conduct a boat-

based spotlight survey at night is essential to determine the population size of crocodiles in the lake, and since permission was not given due to security reasons, we were unable to do so.

For the winter months, “ground cover”, “visual cover”, “floating vegetation”, and “gravel-clay”, had positive effect on lakeshore use. The effect of these covarites can be well explained. Presence of ground cover such as grasses, shrubs and reeds could provide the animal with areas which could conceal the animal. This concealment was also possible mainly due to the height of the vegetation, or the visual cover that this vegetation provided. Both lakeshore vegetation and floating vegetation are an excellent form of concealment from both prey and human activities. Crocodiles being ambush hunters are well adapted to use floating vegetation as a cover in water. Therefore, floating vegetation, ground cover and visual cover can be used by the crocodiles not just to escape from human disturbances, but also as a form of ambush while hunting prey on land (Someewara, 2011). The covariate “gravel-clay” was suitable for vegetation to grow in as opposed to a rocky substrate. Therefore, “gravel-clay” is assumed to have an indirect effect on lakeshore use.

During summer, certain covariates completely disappear from the lake. Floating vegetation dries up completely and the water recedes extensively, so the lake was devoid of canopy cover. The models suggest that “ground cover”, “slope”, and “visual cover” play a role in determining lakeshore use in the summers. However, only “slope” was shown to have a slight positive effect on the occupancy of crocodiles in the lake. This corresponds with the ecology of the Mugger. Muggers start to construct burrows extensively from the month of March as they begin to lay their eggs from this month. The crocodiles tend to dig burrows at a height to keep their nests from being flooded by water in the monsoon and therefore we see slope dictating the presence of crocodiles in the lake. Also, ground cover and visual cover shows slight positive effect on occupancy as well and the reason for this is similar to the situation in the winters. Crocodiles tend to use vegetation as form of cover as human presence is significantly uniform throughout the lake, in the summers. Therefore, a combination of slope, ground cover, and vegetation cover would seem to indicate areas that are occupied by crocodiles.

As the water recedes extensively in the summer, more land is available for the crocodiles to use in the form of basking or building nests. Therefore it appears that the lakeshore use increases in the lake. Also, the social structure of Muggers determines the lake shore use (Whitaker and Whitaker, 1989). As the breeding season is in effect in April, dominant animals hold onto favourable areas while subordinates wander in search of less favourable areas (Whitaker and Whitaker, 1989). This is likely why lake shore use of muggers seemed to increase.

An important consideration must be made on the activity pattern of crocodiles. Even though the lake is extensively used by human and there are severe disturbances, the occupancy in the lake is not low. This can be attributed to the nocturnal nature of most crocodiles. Even though the area might be occupied by humans in the daytime, the crocodiles might just use the same area at night, when humans cease their work.

More detailed work needs to be done to arrive at a conclusive answer; however, we were able to establish a general model of lakeshore use by crocodiles and we were able to detect the effect of seasonality on occupancy in a severely disturbed lentic system. Therefore, it can be said with some confidence that the activity pattern of crocodiles, presence or absence of covariates due to changing seasons, and the social structure or hierarchy in crocodiles, all play a role in determining lakeshore use.

Recommendations

There have been 2 reports of human-crocodile conflict in recent times. Both the victims of the attack have recovered from their wounds and are still using the lake for their daily needs. These attacks had occurred in the dry season, which corresponds with the breeding season of Muggers and they tend to be relatively more aggressive and territorial.

The lake is heavily used by people in the dry season and the chances of an encounter with a large, and aggressive crocodile is higher. We have also found that presence of vegetation cover in the water is correlated highly with the presence of a crocodile. It would be advisable to create awareness in the local village surrounding the lake about these particular findings from the work. Awareness programmes can focus on certain activities such as:

- Avoid areas venturing into water with thick floating vegetation present on the water surface.
- Keeping a safe distance from crocodile dens.
- Not to disturb the crocodiles especially in the dry seasons as that period coincides with the breeding period for Muggers in this area.

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Plate 1: Tables

Model	AIC	Delta AIC	AIC wgt	Model likelihood	No. Par	-2*LogLike
psi(ground cover),p(rock)	162.63	0	0.2393	1	4	154.63
psi(visual cover+ gravel_clay),p(rock)	163.1	0.47	0.1891	0.7906	5	153.1
psi(visual cover),p(rock)	163.17	0.54	0.1826	0.7634	4	155.17
psi(ground cover+ visual cover),p(rock)	164.37	1.74	0.1002	0.419	5	154.37
psi(visual cover+ float veg),p(rock)	164.73	2.1	0.0837	0.3499	5	154.73
psi(visual cover+ water depth),p(rock)	165.16	2.53	0.0675	0.2822	5	155.16
psi(visual cover+ float veg+ water depth+ gravel),p(rock)	165.6	2.97	0.0542	0.2265	7	151.6
psi(water depth + float veg),p(rock)	165.93	3.3	0.0459	0.192	5	155.93
psi(visual cover+ float veg+ water depth+ ground cover),p(rock)	167.29	4.66	0.0233	0.0973	7	153.29
psi(visual cover+ float veg+ water depth+ human act),p(rock)	168.31	5.68	0.014	0.0584	7	154.31
psi(.),p(.)	178.91	16.28	0.0001	0.0003	2	174.91

Table 1- A table showing the different models that were run to explain occupancy in the month of February.

Model	Parameters	beta_est	S.E
psi(ground cover),p(rock)	Psi	0.850026	0.459277
	psi.g_cover_std.	0.602868	0.4684
	P[1]	-1.01957	0.283152
	P[1].Rock	1.954899	0.473774
psi(visual cover+ gravel_clay),p(rock)	Psi	-0.0474	0.716624
	psi.visual_cover	0.517703	0.563761
	psi.gravel_clay_inten	0.369457	0.276293
	P[1]	-1.02151	0.285799
	P[1].Rock	1.945583	0.472321
psi(visual cover),p(rock)	Psi	0.797202	0.432499
	psi.visual_cover	0.544015	0.542033
	P[1]	-0.99159	0.282621
	P[1].Rock	1.933958	0.476678
psi(ground cover+ visual cover),p(rock)	Psi	0.834565	0.451748
	psi.g_cover_std.	0.456005	0.52741
	psi.visual_cover	0.296044	0.594068
	P[1]	-1.00424	0.283845
	P[1].Rock	1.94581	0.475758
psi(visual cover+ float veg),p(rock)	Psi	0.552061	0.554091
	psi.visual_cover	0.581186	0.564466
	psi.float_veg	0.567374	0.863365
	P[1]	-0.98466	0.281962
	P[1].Rock	1.926105	0.476934
psi(visual cover+ water depth),p(rock)	Psi	0.796808	0.432399
	psi.visual_cover	0.549788	0.543812
	psi.water_depth	0.047287	0.414493
	P[1]	-0.99134	0.282618
	P[1].Rock	1.933875	0.476679

Table 2: A table for the month of February, showing the value of beta estimates and the standard error for each parameter.

Model	AIC	deltaAIC	AIC wgt	Model Likelihood	no.Par.	-2LogLike
psi(slope),p(ground cover)	206.24	0	0.2353	1	4	198.24
psi(ground cover),p(ground cover)	206.55	0.31	0.2015	0.8564	4	198.55
psi(slope+ visual cover),p(ground cover)	206.76	0.52	0.1815	0.7711	5	196.76
psi(slope+ ground cover),p(ground cover)	207.91	1.67	0.1021	0.4339	5	197.91
psi(slope+ visual cover+ ground cover),p(ground cover)	208.27	2.03	0.0853	0.3624	6	196.27
psi(.),p(.)	208.29	2.05	0.0844	0.3588	2	204.29
psi(ground cover+ visual cover),p(ground cover)	208.5	2.26	0.076	0.323	5	198.5
psi(slope+ visual cover+ rock),p(ground cover)	210.12	3.88	0.0338	0.1437	6	198.12

Table 3: A table showing the different models that were run to explain occupancy in the month of February.

Model	Parameters	beta_est	S.E
psi(slope),p(ground cover)	Psi	3.264798	1.794994
	psi.slope	1.632789	1.522946
	P[1]	0.095956	0.18172
	P[1].g_cvr_std	0.535574	0.1836
psi(ground cover),p(ground cover)	Psi	1.963056	0.628183
	psi.g_cvr_std	0.635824	0.626857
	P[1]	0.193148	0.192047
	P[1].g_cvr_std	0.391187	0.204901
psi(slope+ visual cover),p(ground cover)	Psi	4.424849	2.703064
	psi.slope	2.703051	2.239758
	psi.vis_cvr	1.027895	1.085572
	P[1]	0.096583	0.179388
	P[1].g_cvr_std	0.538877	0.180586
psi(slope+ ground cover),p(ground cover)	Psi	2.047381	0.690733
	psi.slope	0.491145	0.663247
	psi.g_cvr_std	0.691617	0.679104
	P[1]	0.18522	0.196686
	P[1].g_cvr_std	0.412462	0.217331

Table 4- A table for the month of April, showing the value of beta estimates and the standard error for each parameter.

Plate 2: Pictures

Map of the study area



Figure 1- A map showing the city of Mumbai with the location of Vihar lake inside Sanjay Gandhi National Park.



Figure 2- A closer view of the lake inside Sanjay Gandhi National Park. The blue grids indicate different segments in the lake.

Signs- Tracks, Scats, Burrows, and Direct Sighting



Figure 2.1- A photograph of the front foot, hind foot, and tail tracks of a crocodile.



Figure 2.2 - Photograph of a typical crocodile scat.



Figure 2.3- Various burrows or dens that were dug by Muggers in a small stretch of the lake.



Figure 2.4- A photograph showing the tracks of a crocodile and its belly mark as it was resting, before it entered the water as we approached it.



Figure 2.5- A large Mugger basking partially out of water.



Figure 2.6- Evidence of trial burrows being dug in such rocky substrate.



Figure 2.7- Track of a giant Mugger. Each band on the Robel pole is equal to 2 cm. The track covers almost 26 cm. The approximate size is considered to be 12.3 ft long.



Figure 2.8- A burrow being dug beneath a patch of Ipomea weed.



Figure 2.9- A photograph showing the tracks of a crocodile heading into water.



Figure 2.10- A photograph showing a couple of scats in the same area.



Figure 2.11- An individual that was sighted on land and immediately fled to the safety of the water. The crocodile was approximately 9ft. long.



Figure 2.12- A relatively small 4ft. individual. The crocodile was basking on a rock substrate before moving into the water as we approached it.

Measuring Covariates



Figure 3.1- A patch of Ipomea in the northern part of the lake where floating vegetation was especially dense.



Figure 3.2- The eastern side of the lake with gentle slope and presence of floating vegetation.



Figure 3.3- Method of calculating visual obstruction. One observer holds the Robel pole while the other observer tries to look at the bands on the pole from a distance of 7m and a height of 1m above the ground.



Figure 3.4- Water depth being measured using the Robel pole at a distance of 1m from the shoreline.



Figure 3.5- Canopy cover was calculated by estimating the percentage area that the canopy occupied in the photograph.



Figure 3.6- A photograph showing ground cover in the form of Grass, and also a crocodile partially on land in the distance.



Figure 3.7-A photograph indicating Rocky substrate type with tree/shrub as ground cover

Human Activities



Figure 4.1- People on a small piece of land where alcohol brewing regularly takes place.



Figure 4.2- A group of fisherman preparing food in the lakeshore area.



Figure 4.3- A group of kids playing and swimming in the water. A crocodile was observed in the area on the same day almost two hours before the arrival of this group.



Figure 4.4- Cattle grazing is another form of human activity and this was recorded in the northern side of the lake.



Figure 4.5- People collecting herbaceous plants and grasses for local consumption.



Figure 4.6- An embankment in the south eastern side of the lake showing high intensity of human activity. People often bathe and wash clothes in this part of the lake.



Figure 4.7- Religious practices such as immersion of idols are carried out in the lake during the time of various festivals.



Figure 4.8- A large cauldron which is used to brew alcohol from sugarcane.



Fig 4.9: Intensive alcohol brewing is seen in the month of April