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Habitat use of King Cobra (*Ophiophagus hannah*) in a heterogeneous landscape matrix in the tropical forests of the Western Ghats, India

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ABSTRACT.– **King Cobras are the largest of all venomous snakes. Thus, they have a unique role in the ecosystem. We sampled habitat locations of five radio-tagged King Cobras in the Western Ghats of Karnataka, India, from December 2010 to April 2011. Habitat preferences were investigated based on use of retreat sites from radio-implanted animals. While sampling for known retreat sites, 30 additional sightings of wild adult non-radio-tagged King Cobras were recorded. Sex based differences in habitat use were studied by sampling nest sites. The data were analyzed using generalized linear models (GLM) for the binary presence dataset. We found King Cobra movement patterns are strongly influenced by ambient temperature, relative humidity and wind direction. King Cobras did not show strong preferences for any particular habitat type. King Cobras likely prefer areas close to streams with abundant fallen logs as retreat sites. Animal burrows were also used as shelter sites. Areas with a leaf litter depth of 10–17 cm were preferred sites for nest construction.**

KEYWORDS.– **King Cobra, habitat selection, snakes, *Ophiophagus hannah,* Western Ghats, Agumbe**

Introduction

Thermal environment has repeatedly been shown to be a strong driver in snake activity patterns (Schwaner 1989; Fitzgerald *et al*. 2002, 2003). Yet, snakes are highly adaptable, ranging from near arctic conditions to the tropics. Snakes, as poikilotherms, are intertwined with the surrounding thermal environment. Thus, they must adapt behaviorally depending upon the range of suitable temperatures of their habitats (Huey 1982). The effectiveness of this behavioral thermoregulation varies with thermal quality and evidence suggests that poikilotherms thermoregulate more effectively when the thermal quality is low (Blouin-Demers & Weatherhead 2001; Blouin-Demers & Nadeau 2005). Differences in thermal quality significantly influence site use on the canopy level in a forest, or open rock faces or underground burrows (Webb & Shine 1998). These are attributes of seasonal variation (Slip & Shine 1988; Goode *et al*. 2009). Habitat use in snakes varies with sex and between gravid and non-gravid females (Madsen 1984; Charland & Gregory 1995; Brown & Weatherhead 1999) In addition, prey availability has been observed to influence habitat use

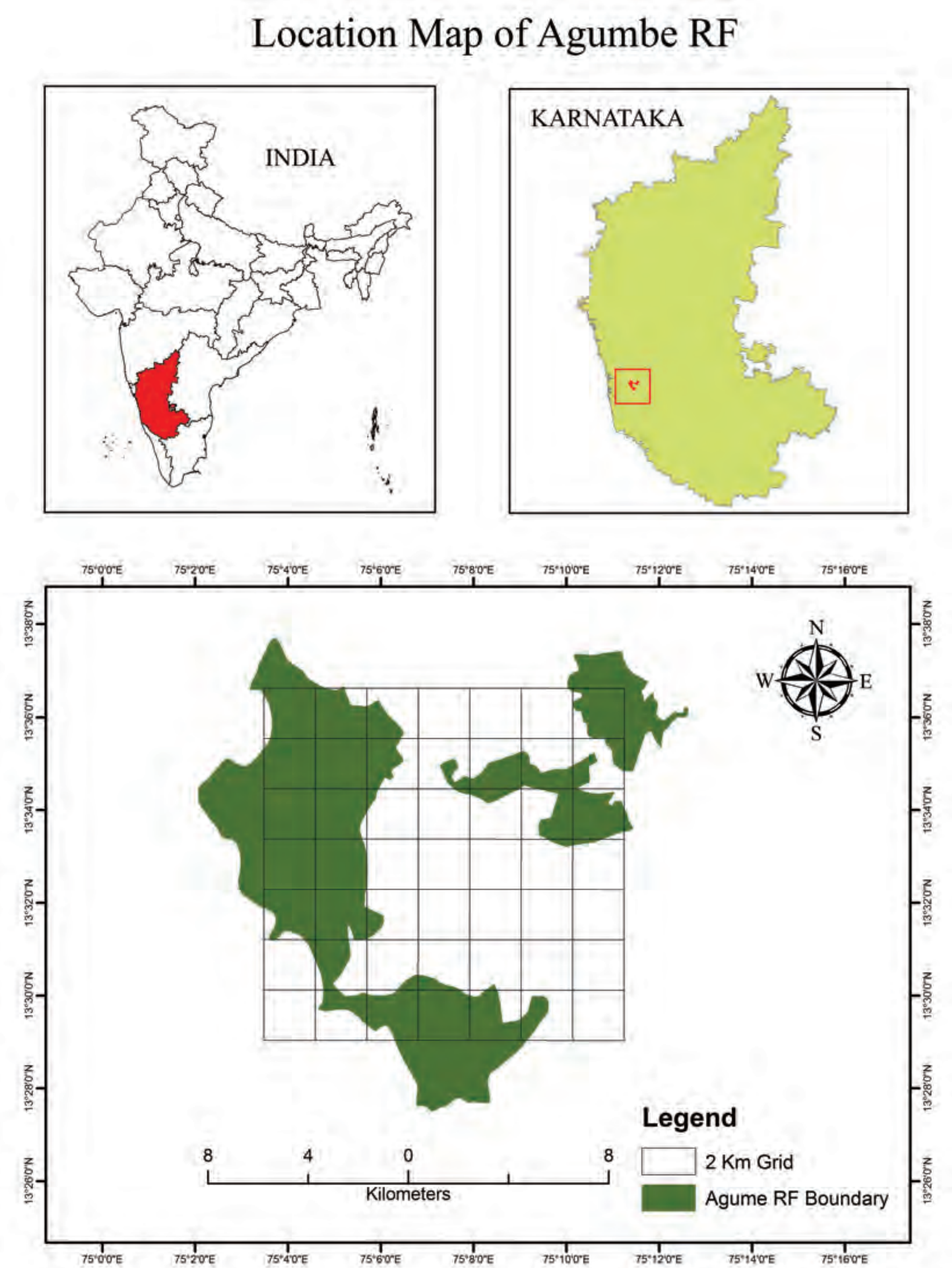

Figure 1. Location of study area; denoting the size of sampling grid within the study area and the subsequent reserve forest.

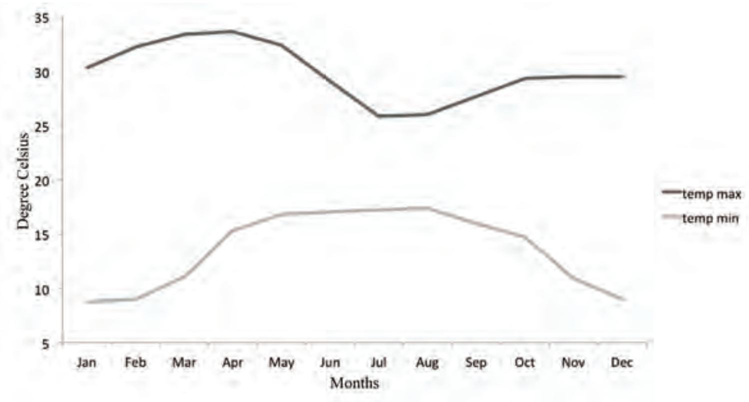

Figure 2. Annual temperature regime at Agumbe.

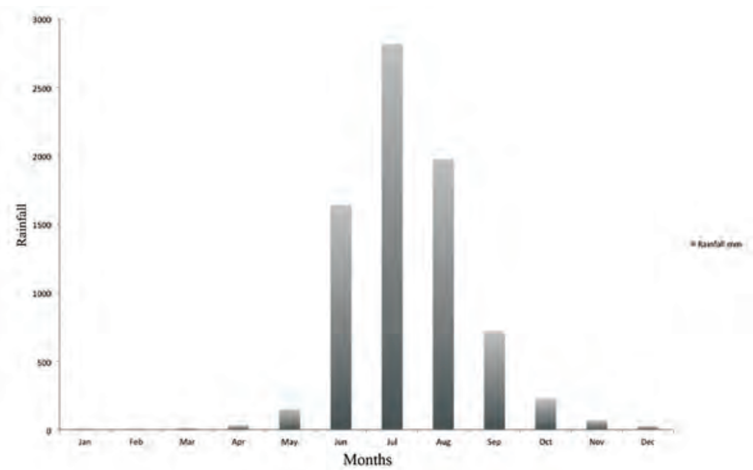

Figure 3. Annual rainfall regime in Agumbe. The peaks are mostly from June to August, measuring rain as high as 3000mm

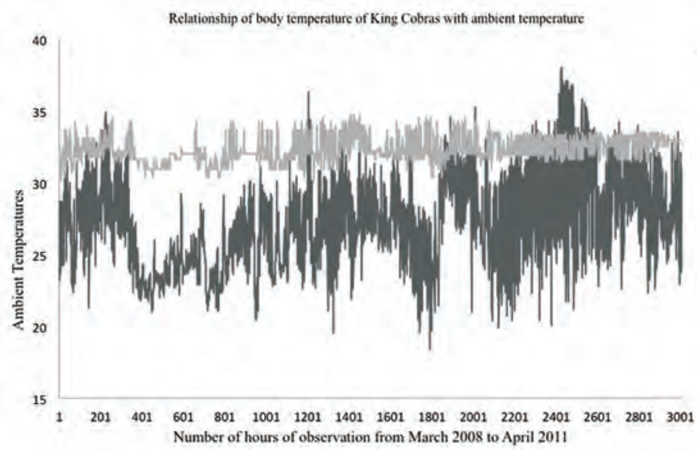

Figure 4. Body temperature (Tb) and ambient temperature graphs (Ta) forOPHA ID snake F1; OPHA ID snake M1; OPHA ID snake M2; OPHA ID snake M3 and OPHA ID snake M4. The number of hours of observations is on the x-axis and temperatures are on the y-axis. Tb remains more-or-less constant despite fluctuations in Ta. Based on observations made from March 2008 to April 2011.

(Klauber 1972; Weatherhead & Charland 1985; Daltry *et al.* 1998; Theodoratus & Chiszar 2000; Bhaisare *et al.* 2010). Behaviors such as mate selection, competition for natal areas, foraging, and reproduction (Brito 2003; Waldron *et al.* 2006) are ecological influences on habitat site selection of snakes. Habitat use may vary extensively amongst sympatric species (Keller & Heske 2000). Within a particular sex, as observed by Pattishall & Cundall (2009), there is often site fidelity with respect to nesting sites. Certain snakes seem to use suitable ambush sites, depending upon the thermal situation and relative humidity (Daltry *et al.* 1998; Oliveira & Martins 2001). Many snakes use underground burrows as hibernacula or for nesting (Steen *et al.* 2007; Ramesh & Bhupathy 2010a). In human modified landscapes, snakes use retreat sites such as abandoned construction sites and utilize roads as thermoregulatory surfaces (Daltry *et al.* 1998). Most importantly, habitat use of snakes is usually multidimensional and habitats are used in a complex manner (Hebrard & Mushinsky 1978).

The King Cobra (*Ophiophagus hannah* Cantor, 1836) is a largebodied snake occurring in South and Southeast Asia (Aagaard 1924). Throughout its range, the King Cobra occurs in a wide variety of habitats from littoral, mangrove swamps to broadleafed alpine forests (Bashir *et al*. 2010). Although much anecdotal information has been recorded as reviewed by Das & Whitaker's (1996), detailed studies are lacking for this species. The King Cobra is considered an apex predator occurring in a variety of habitats, however, the nature of its habitat selection strategy is poorly understood. The diurnal and seasonal eco-geographical requirements for predation and other life history traits are unknown. Much of the Western Ghats biodiversity hotspot is under threat of deforestation. Currently, the effects of deteriorating forest quality and the expanding human habitations on King Cobra ecology are unknown. This was one of the major pretexts for the King Cobra Telemetry Project in South India and for this study in particular.

Material and Methods

Study Site.– Fieldwork was performed in Agumbe (13.5087° N, 75.0959° E; 716 m a.s.l.), located in the Central Western Ghats of the Shimoga District, Karnataka, India (Fig. 1). The Agumbe Rainforest Research Station (ARRS) has been conducting King Cobra research through the King Cobra Telemetry Project (KCTP) since March 2008. The area is considered tropically seasonal but has a heavy rainfall bout and cold winter and hot summer regimes. Monsoons occur from June to September and the area receives 1500–3000 mm of rain during the monsoon season (Fig. 2) and humidity levels are high and relatively stable at above 75%, reaching 95% during the monsoon. The cold season lasts from December–February and has a temperature range from 15–35°C (Fig. 2). The hot dry season is usually from March–May and is characterized by lower humidity and temperatures that are above 35°C. Champion & Seth (1968) classified these forests as the West Coast Tropical Evergreen forest (1/A-C/4). Forest areas are dominated by tree species of the genera *Dipterocarpus*, *Diospyros*, *Humboldtia* and *Artocarpus* (Pascal 1988). However, many areas surrounding the Agumbe reserve forest have been converted to plantations (Acacia, Areca nut and Banana), or rice and wheat paddy fields. Thus, the landscape is a complex mosaic of habitat types, including natural forests, paddy fields and plantations.

The Intensive Study Area (ISA) of 96 km^2 encompasses previous presence location records of these radio tagged snakes. The ISA was divided into 49 grids of 2 km^2 each (Fig. 1) and was sampled for habitat variables relating to the presence of King Cobras. Secondary records of

Table 1. GLM values of coefficients with their standard errors at a population level for King Cobras.

Variables	coefficients
TA	7.7e10-1 ± 0.06
RH	1.25 ± 1.14
SW-NE	1.19 ± 2.6e10+3
S-N	0.21 ± 0.42
SE-NW	-5.36 ± -0.54
E-W	-4.77 ± 3.31e10+2
W-E	-4.69 ± 3.5e10+2
N-S	-4.57 ± 1.6e10+3
NE-SW	-4.517 ± 1.9e10+3
NW-SE	-3.99 ± 1.5e10+3

Table 2. Habitat use vs. availability results of the four radio tagged King Cobras.

Rank	Habitat type	Average	LCL	UCL	Standard Error
1	Evergreen Forest	0.19	-0.1	0.48	0.02
2	Deciduous Forest	-0.1	-0.48	0.29	0.1
3	Plantation/Orchard	-0.16	-0.83	0.51	0.34
4	Scrub/Deg Forest	-0.33	-1.09	0.43	0.38
5	Agriculture	-0.53	-1	-0.04	0.18
6	Grassland	-0.65	-1.21	-0.09	0.28
7	Water bodies	-0.72	-1.27	-0.18	0.27

Table 3. GLM with microhabitat variables with presence as a response variable to different microhabitat variables in a retreat site during the present study. Significant values (< 0.05) are indicated in bold.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.16e+00	4.4e-01	2.667	0.00766
Burrow	-7.24e-01	4.31e-01	-1.682	0.09249
Edge of Stream	1.67e+01	1.33e+03	0.013	0.98997
Tree Trunk	1.69e+01	1.76e+03	0.010	0.99230
Bamboo Thicket	1.69e+01	2.509e+03	0.007	0.99463
Distance from stream	7.51e-03	3.310e-03	2.266	0.02344
Dead Vegetation	-2.05e-02	6.712e-03	-3.043	0.00234
Fallen Logs	2.333e+00	5.113e-01	4.551	5.35e-06

Table 4. Final GLM for King Cobra nest site with presence as a response to various microhabitat variables. Significant values (< 0.05) are indicated in bold.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-7.35	2.86513	-2.565	0.0103
SC	0.022	0.02247	0.945	0.3445
CC	0.039	0.03320	1.169	0.2426
LL_DEP	0.65	0.30998	2.073	0.0381

110 wild non-tagged King Cobras from March 2008 to October 2010 as well as points located within the grid were used for presence analysis. All habitat points were recorded using a Garmin 72H GPS.

Retreat sites sampling.– Retreat sites were identified as areas where tracked King Cobras remained stationary for an entire night, in addition to sites revisited more than once by the animal. All retreat sites were within the intensive study area grid boundaries. We located additional retreat sites, along with the locations of tagged animals, based on sightings from December 2010 to April 2011. Ambient temperature (TA) (Schwaner 1989; Row & Blouin-Demers 2006) and relative humidity (RH) (Daltry *et al*. 1998) as well a wind speed and direction were measured within a 10 m radius of each retreat site with a Kestrel 3000 Wind Meter. We also attempted to categorize and quantify habitat covariates, habitat type, percentage shrub cover (Madsen 1984; Weatherhead & Charland 1985), and percentage dead vegetation on site. Canopy cover was measured using a spherical densitometer. We recorded land characteristics including: burrows (BURR), fallen logs (F_LOG), leaf litter depth (LL_DEP), distance from nearest water source (DIST_STREAM), distance to nearest burrow (DIST_BURR), distance to the nearest fallen log (DIST_FLOG), and distance to the nearest rock (DIST_ROCK) using a flexible field measuring tape

Nest site sampling.– Our field study period partially coincided with the King Cobra breeding season from March to late April 2011. Because King Cobra females are the only snakes in the world that make a nest, we wanted to find out whether any particular habitat parameter influenced nest site selection. We also engaged the local people to search for King Cobra nests in the area. At each nest site location (n = 13), habitat covariates within a 10 m radius were sampled. Recorded variables were GPS location in Universal Transverse Mercator (UTM) format, habitat type (HAB_TYPE), shrub cover (SC), dead vegetation (DV) and canopy cover (CC). Measurements were also taken at four random locations at 50 m distances from each nest site.

Radio Telemetry.– The KCTP collected data from March 2008 until April 2011. Five snakes (ID: F1, M1, M2, M3 and M4) were tagged and followed. The transmitters (Holohil systems; model AI-2T, weight 24 grams) used for the snakes varied in frequency. The transmitters were implanted into the coelomic cavity (Weatherhead & Anderka 1984).

Snakes were tracked for varying amounts of time; only one snake ID OPHA M4 was successfully tracked to the study completion. Body temperatures of the snakes were recorded using an inbuilt thermal sensor in the transmitter. Wind direction, ambient temperature (TA) and relative humidity (RH) were also recorded during tracking using a Kestrel 3000 Wind Meter. At each retreat site selected by M4, location in UTM coordinates and the major habitat type, and microhabitat variables were recorded. These data were collected from 08h00–16h00, depending upon the activity period of the animal for the given day. If the snake moved then it would be followed and monitored until it selected a retreat site.

Land Use Land Cover (LULC) Map.– A 1:250 000 land use land cover map was derived from the Indian Remote Sensing Satellite (IRS 1D) Linear Imaging Self-scanning Sensor (LISS) III image. The spatial resolution was degraded from 23.5 m to 62.5 m. The LISS III data for the year 2005 was used to classify land use land cover (LULC) map. The classified habitat types in the LULC map are as follows (IIRS report 2002): evergreen forest, deciduous forest, plantations/orchards, scrub forest, agriculture — mostly rice and wheat cultivation, grassland — areas mostly covered by grass species or clearings and water bodies. This map was later used to analyze habitat use by radio tracked King Cobras.

Retreat and Nest Site Selection Data Analysis.– We used generalized linear models (GLM) with a logit link function (for binomial errors) to analyze the data, as appropriate for a binary dataset with categorical variables (Crawley 2007). To investigate the factors influencing retreat site selection, presence/absence (binary response) data along with habitat predictors were collected from 262 presence points.

Microhabitat sites (n = 262) and nest sites (n = 13) were checked for correlations using a Spearman Correlation test. Of the highly correlated variable pairs, the ecologically less meaningful and redundant variables were removed from the models. Variable correlated above a value of 0.4 were removed from all models. A full logistic regression model with linear predictors (microhabitat variables) was constructed and then reduced using backward selection. The AIC (Akaike Information Criterion) was used to select the most parsimonious model. The regression coefficients were verified using univariate logistic regression of predictors (microhabitat variables) to infer direction size effect and significance of microhabitat variables on the probability of King Cobra presence/absence.

Habitat Use vs. Availability: Analyzing Movement Pattern.– Habitat use of radio tagged snakes was computed using Jacob's Index (1974). A generalized linear model framework (GLM- logit link and binomial error, i.e., logistic regression) was computed. Movement vs. no movement (binary response) was modeled with environmental parameters such as ambient temperature (TA), relative humidity (RH), wind speed and wind direction and their combinations/interactions to understand movement patterns. Movement data were used from tagged snake M4. To improve the sample size, datasets from the KCTP (March 2008–December 2010), were also used. All analyses were performed in *R* version 2.11.1 (R Development Core Team 2008).

Results

Using generalized linear models to predict the influencing variable on movement pattern we selected the most parsimonious model using AIC values (see Table 1). Ambient temperature (7.7e10-1 ± 0.0545, $P < 0.001$; range 20–35°C) has the greatest influence on movement, followed by relative humidity (1.25 ± 1.14, $P = 0.01$; range 70–90%). Since King Cobras are chiefly diurnal, 87% of activity was observed from 10h00 hours (thermoregulation) to 18h00 hours (return to retreat sites), although when they would seek cover in their retreat sites at approximately ~12h00. Some observations (n=3) were during night hours, primarily when the snake was foraging.

Habitat use was ranked with significance values derived from the index as per their average values (see Table 2). The ranked habitats were as follows: evergreen forest (~83%) > plantation/orchard (~7%) > scrub/degraded forest (~4%) > agriculture (~3%) > (grassland ~1%) > water bodies (~1%) ($P < 0.001$). Here water bodies imply major reservoirs, rivers and canals, and excludes forest streams and rivulets. During the breeding season, March to April of 2011, we encountered a higher number of King Cobras around human habitations (n= 21).

We sampled a total 262 presence locations in which Fallen Logs (0.02, Z= 4, $P < 0.001$), Dead vegetation (P = 0.002) and distance to streams (P = 0.02) show the maximum influence on the presence of a King Cobra at a site. A large number of occurrences of King Cobras in burrows was also documented (n=57, 21%). These microhabitat sites were distributed across the landscape of the study area. However, presence locations were higher (>70%) in sites located close to forests or in the forests. We observed one active nest during the sampling session wherein we could see that areas with higher leaf litter were chosen as suitable sites for building nests. Also from the generalized linear model, LL_DEP (Leaf Litter Depth) proved to be a significant factor influencing nest site selection (0.65, Z = 2, P = 0.03; leaf litter depth of 10–17 cm).

Discussion

Movement Pattern: Behavioral Thermoregulation.– Numerous studies on habitat use or activity patterns of ectothermic animals have highlighted the importance of behavioral thermoregulation (Schwaner 1989; Fitzgerald et al. 2002). Body temperatures often show distinct variation in summer and winter seasons in the temperate region (Schwaner 1989). However, the biology of snakes in thermally stable environments, such as warm water bodies or the humid tropics, has rarely been investigated. Shine & Lambeck (1985) demonstrated that aquatic filesnakes, Acrochordus arafurae, maintain a mean body temperature of 26–30°C by passively thermoconforming. A radio-telemetric study of water pythons, Liasis fuscus, concluded that they maintained body temperatures of around 30°C, again without apparent thermoregulatory behaviour (Shine & Madsen 1996). King Cobras show a considerable response to ambient temperatures. In this case, individuals were observed maintaining their body temperatures within a fixed range (max of about 30°C) (Fig. 4). These results concur with the findings in some other snake studies in tropical ecosystems (Lilywhite 1987; Shine 1987; Schwaner 1989; Shine & Madsen 1996; Ramesh & Bhupathy 2010a).

While the relation of snakes with their ambient temperature is well understood, relative humidity has been found to be a factor of greater influence on King Cobra movements. Similar results have been seen in Malayan Pit Vipers (*Calloselasma rhodostoma*) which exhibit no basking thermoregulatory behavior and are primarily influenced by relative humidity (Daltry et al. 1998). A direct influence of humidity on King Cobras may be answered by the fact that many areas of the Western Ghats show very high levels of humidity. Thus proximity to water may be important for avoiding desiccation thanks to highly humid conditions (Huey 1982). Reptiles, especially species in dry tropical areas, can lose a substantial amount of water through their skin (Heatwole 1976). High water loss was also observed during ecdysis in snake M4, as is typical for many reptiles (Heatwole 1976; Shankar & Whitaker 2009).

The influence of wind direction on movement pattern may in part, be due to the predatory strategy of King Cobras (S. Rachakonda, pers. obs). King Cobras have excellent cognitive abilities and have been observed to use scent trails to search for and locate prey in addition to finding mates (pers. obs.).

The apparent influence of relative humidity and wind direction on King Cobra movement patterns sheds new light on the ecology of this tropical species. Most snake behaviour studies have been conducted in areas with greater temperature extremes, where behavioural thermoregulation may be extremely important (Blouin-Demers & Weatherhead 2001; Blouin-Demers & Nadeau 2005). Shine & Madsen (1996) rightly pointed out that the vast majority of species inhabit the tropics, and further studies in this region may ultimately negate the common assumption that thermoregulation is of paramount importance in the daily life of most reptiles.

Habitat Use In Relation to Thermoregulation.– Snake habitat use is a function of many factors operating on a micro-scale (Prior & Weatherhead 1994). These factors influence snakes even at population levels (Reinert 1984). The empirical results for habitat utilization show that King Cobras use a variety of habitats opportunistically and the Jacob's Index shows most habitats as 'neutral'. King Cobras did not actively prefer or avoid any particular habitat type in the study area, which is a mosaic of habitat types. Diversified habitat types typically have a diversity of snake species (Shine & Fitzgerald 1996; Blouin-Demers & Weatherhead 2001).

Since King Cobras prey exclusively on other snakes, it can be assumed that they move mostly in search of prey, even in the human dominated landscape. Coinciding with this is the fact that a prey species favored by King Cobras; the Indian rat snake, *Ptyas mucosa*, was the most observed snake within the habitat mosaic.

King Cobras select retreat sites based on the availability of basking and cover. The amount of sunlight varied significantly during the course of the day. However, these snakes only came out during certain times of the day (forenoon and late afternoons), likely avoiding midday and early afternoon basking, thus exhibiting bimodal thermoregulation. Nevertheless, these snakes are very alert during most of the time spent basking and would retreat immediately beneath a fallen log or into dead vegetation at the slightest hint of disturbance. Indeed, a number of snake studies have highlighted the importance of behavioural thermoregulation. For example, snakes are often observed spending extended periods basking or exploiting cool micro-habitats. Thus, maintaining body temperature within a narrow range (Schwaner 1989). Broad-headed snakes, *Hoplocephalus bungaroides*, are restricted to sandstone rock outcroppings in Australia, where exfoliated boulders of different sizes and thicknesses provide a suite of retreat-sites with variable thermal characteristics. Sheltering snake body temperatures under rocks are determined by the degree of shading and the thickness of the rock (Webb & Shine 1998). The Indian Rock Python (*Python molurus molurus*), during a study performed in Keoladeo Ghana National Park in India by Bhupathy & Vijayan (1989), showed bimodal activity patterns with respect to external temperature. These animals however, used burrows, coming out in the morning hours to bask and retreating during evening hours. They also were found to use different burrows or hibernacula (as winter hibernating sites) and some individuals were seen using tree tops to perhaps reach the desired body temperature, as observed in Carpet Pythons, *Morelia spilota*, in coastal eastern Australia (Shine & Fitzgerald 1996).

Our research is limited to adult individuals. Juvenile King Cobras are likely to use habitats differently as they face a higher risk of mortality due to predation and starvation. Since the external temperature remains more or less constant, fallen logs may provide excellent cover and basking sites as they may provide the appropriate thermal quality and camouflage (Row & Blouin-Demers 2006). Hiding within the dead vegetation can also be an ambush predatory tactic as seen in vipers. A preference for fallen logs that provide a linear hiding place was observed, and often they exhibited basking behavior with their body sprawled rather than coiled (pers. obs.). King Cobras observed near human habitations quickly disappeared inside burrows when disturbed. However it should be noted that these observations made are only of adult king cobras. These results cannot be inferred for juvenile king cobras, as their habitat requirements owing to predation pressure may be entirely different.

Most species of snakes lay their eggs either in burrows (Ramesh & Bhupathy 2010a), leaf litter, or under rocks/fallen logs (Burger & Zappalorti 1988). King Cobras however, are the only species that builds a mound nest comprised of fallen vegetation. Thus, there is a significant predilection in King Cobra females for sites with higher levels of dead vegetation and leaf litter (a range of 10–17 cm) for nest building (Table 5). Leaf litter and other dead vegetation form the perfect substrate for the nest chamber (Dattatri 1987). King Cobra females start building nests in late April and may continue until the first week of May at the study site (G. Shankar, pers. obs). Since these areas receive very high rainfall, it is an important priority for the females to select sites with enough substrate to keep the nest chamber dry. However, certain disturbance factors such as proximity of village, human and livestock presence (Kannan 1993) have not been accounted for while testing habitat preference of these nest sites. Female King Cobras occurring in the north Indian state of Uttarakhand have been observed to begin nest construction in June and remain at the nest site longer compared to the females in the Western Ghats. Nests observed in the state of Mizoram have been found to be different in size and shape (bottle shaped) but interestingly nest-building starts by late April and May, similar to populations occurring in the Western Ghats (G. Shankar, pers. obs).

Fortunately, despite the proximity of the snakes to human dominated areas, there is evidence of high tolerance by the local people towards King Cobras and they refrain from killing them. This stems from the religious belief that people have towards the King Cobra, which is worshipped in Agumbe. This is evident through presence of snake idols across the landscape. Such tolerant attitudes can be important catalysts in aiding the conservation of this fascinating apex level predator. Since the Western Ghats is a unique landscape, it would also be interesting to know how King Cobras live in other areas of their distribution and how the ecology varies geographically. It would be useful to study King Cobra populations occurring in other habitats such as littoral forests and broad-leaved forests (Bashir *et al*. 2010). This would enable us to understand the adaptability of this species to gradual events such as climate change as well as the rapid deterioration of their habitats.

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