FACTORS INFLUENCING MOVEMENT PATTERN, HABITAT USE AND DISTRIBUTION OF KING COBRA (*Ophiophagus hannah*)- A MULTISCALE APPROACH

DISSERTATION SUBMITTED TO SAURASHTRA UNIVERSITY, RAJKOT, IN PARTIAL FULFILMENT OF THE MASTER'S DEGREE IN WILDLIFE SCIENCE

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BY

CHETAN. S. RAO

UNDER THE SUPERVISION OF

DR. GAUTAM TALUKDAR

&

PROF. B.C. CHOUDHURY

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

"If the account given in Genesis is really true, ought we not, after all, to thank this serpent? He was the first schoolmaster, the first advocate of learning, the first enemy of ignorance, the first to whisper in human ears the sacred word liberty,"

- Robert. G. Ingersoll

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Certificate

This is to certify that **Mr. Chetan Rao** has carried out an original piece of research in partial fulfilment of Master's Degree in Wildlife Science of the Saurashtra University, Rajkot. The topic of his dissertation is **"Factors influencing movement pattern, habitat use and distribution of King Cobra (*Ophiophagus hannah*) - a multiscale approach"**. The study was carried out under our supervision from December 2010 to June 2011. We hereby certify that this work has not been submitted for any degree to any university.

Dr. Gautam Talukdar
Scientist-C
Supervisor

Prof. B.C.Choudhury
Scientist- G
Co-supervisor

Date:

Place: Dehradun

पत्रपेटी सं0 18, चन्द्रबनी, देहरादून – 248 001, भारत
Post Box No. 18, Chandrabani, Dehra Dun - 248001. INDIA
ई.पी.ए.बी.एक्स : + 91-135-2640111 से 2640115 फैक्स : 0135-2640117, तार : WILDLIFE
EPABX : + 91-135-2640111 to 2640115: Fax : 0135-2640117; GRAM : WILDLIFE
ई–मेल / E-mail : wii@wii.gov.in

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Executive Summary

The king cobra (*Ophiophagus hannah*) is the largest species of venomous snake in the world. It is a widely distributed species occurring in India and Southeast Asia. Most of the habitat use studies of ophidians are responses of ambient temperature. These results are often correlated with temperate areas where there is a significant shift in temperature annually. In tropical ecosystems, to understand ecology of a large bodied species like the king cobra would be interesting, knowing the fact that very little work has been done so far. The objective of my study was to procure relationship of ecographic variables on movement pattern, habitat use and distribution of king cobras at an individual and at a population level.

This study was carried out in Agumbe, Karnataka in the Western Ghats region of India for 4 months during December 2010 to April 2011. Habitat utilization points were sampled throughout the study area, which basically was placed within the boundaries of a 2x2 sq.km grid enclosing all the presence locations collected during five years from the ongoing King Cobra Telemetry Project conducted by the Agumbe Rainforest Research Station and the University of Arizona in collaboration with the Karnataka state forest department.

Retreat sites (n=262) were selected where the tagged (n=5) had been recorded and sampled for microhabitat variables. Nest sites (n=13) were also looked into, to explore site selection by females. A total of 30 ad libitum sightings of king cobras were recorded during the study. Prey density walk was carried out to derive a relative abundance based on encounter rate in the study area that came to be 1.24 animals/km. A total of 9 species of prey were encountered during prey density walks. The kernel estimates and minimum convex polygon for four radio tagged individuals was calculated for home ranges and area vs. availability was computed for habitat preference and use using Jacob's (1974) Index.

The results of this study show a strong correlation of ambient temperature of range 20-35°C (Beta coefficients 7.7e10-1 ± 0.0545) and relative humidity (70-90%) (Beta

coefficients 1.25 ± 1.14) with movement pattern and habitat site selection and also affect distribution patterns of this particular king cobra sub population.

It is also found that king cobras do not particularly obligate themselves to a particular habitat type except for some degree of preference towards evergreen forest. The microhabitat however, influencing king cobra movement and habitat use are fallen logs on the forest floor (Beta coefficients 2.327e+00 ± 5.113e-01) and dead vegetation on the forest floor (Beta coefficients 2.042e-02 ± 6.796e-03) which have a stronger correlation with presence while ground burrows show a negative correlation. Leaf Litter Depth in the forest floor in sites with range of 4-7 inches deep (Beta coefficients 0.64269 ± 0.30998) influences nest site selection.

Using secondary rescue data of five years and all the other presence records for king cobras in the wild, I ran a MaxEnt presence only model (auto model) using only environmental variables taken from BIOCLIM to test environmental parameters influencing distribution. The places of higher precipitation within the study area indicate a higher influence on occurrence and places of higher temperature and aridity regimes does not indicate occurrence of king cobras.

The management recommendations for conserving such large bodied snakes would be a multidimensional approach. The local people within the study area do not kill king cobras, due to religious reasons. However, these attitudes are changing and so also some of the tolerant ideologies of the local people. King cobras have been found to occur more in a landscape matrix dominated by evergreen forests and decline in evergreen forest due to land use conversion could be the emerging possible threats to king cobra in the Western Ghats.

1. Introduction:

Studies on habitat use of snakes have associated strong correlation of habitat use with the ambient temperature of the surrounding environment (Schwaner 1989, 1991; Brito 2003). The habitat use of snakes also depends strongly on sex and females show a distinct specificity for certain sites primarily for nesting like Brownsnakes (*Pseudonaja textilis*) in Australia (Whitaker and Shine 2003) and in Pine snakes (*Pituophis melanoleucus*) (Burger and Zappalorti 1988). A considerable amount of time and energy is spent on activities such as moving amongst sites for basking site selection and then heading back to their retreat-sites. This energy spent would significantly vary with the amount required for activities such as foraging or mate selection. Due to the specificity of their physiological requirement, a strong linear relationship gets established which determine the occurrence and niche of the species and in turn influencing larger demographic factors such as community assemblages and abundance.

Many ophidian species show behavioral traits like aggregation as observed in rattlesnakes (*Crotalus horridus*) and Pythons (*Python spp.*) that use hibernacula for use of cover and many smaller bodied reptiles like Uropeltids (endemic to the Western Ghats) which are fossorial by nature, coming out only during certain time of the day and season when the external ambient temperature seems suitable. The extent of the dependence on the ambient environment varies amongst species (Huey 1982). Some species are thermoconformers that have a wide spectrum of temperature tolerance regimes while some survive only in narrow ranges and are special thermoregulators. The cause of this strategy is the availability of suitable temperature in case of unpredictable environment conditions like in temperate where there is a daily fluctuation of the external temperature and climate. Certain microhabitat types like perches (convection) or an open rock face or on the ground (conduction/radiation) serve as a suitable basking site.

Row and Blouin-Demers (2006) study demonstrated that the thermal quality affects movement patterns, home ranges and habitat use of milk snakes *Lampropeltis triangulum*. The effectiveness of thermoregulation varies with thermal quality, and recent evidence suggests that ectotherms thermoregulate more effectively when the thermal quality is low (Blouin-Demers and Weatherhead 2001; Blouin-Demers and Nadeau 2005). Milk snakes had a strong preference for open habitats, presumably to facilitate behavioral thermoregulation. Habitat use, however, was unaffected by variation in thermoregulatory effectiveness and, instead, milk snakes basked proportionately more to increase thermoregulatory effectiveness when thermal quality was low. This discrepancy, however, could be attributed to ecological factors other than temperature.

In temperate situations where seasons vary considerably, special sites, which provide suitable ambient temperature, is very important. Loss of these habitats because of anthropogenic activities is the largest threat to these species. Broad-headed snakes *Hoplocephalus bungaroides* are restricted to sandstone rock outcrops where exfoliated boulders of different sizes and thicknesses provide a suite of retreat-sites with unique thermal characteristics. Body temperatures of snakes sheltering under rocks are determined by the degree of shading and the thickness of the rock (Webb and Shine 1998). The snakes used the rocks during varying times of the day because they use to 'heat' up very fast. This provided the much required body temperature within their set range. The suitable temperature required for them was ~ 30^{o}C. The varying thickness of the rocks used to determine how 'hot' the rock would get after a certain amount of time. This provided a wide range of areas with their varying degrees of heating to bask and snakes were found to move very little amongst these rocks. Since temperature varied significantly across seasons, the use of these sites varied across seasons. However, changing land use patterns of humans have drastically altered these areas resulting in a dramatic decline in the numbers of this species. In another North American species, the venomous Canebrake Rattlesnake (*Crotalus horridus*) the habitat use was characterized by behaviorally linked activities such as foraging, reproduction and thermoregulation and on the basis of availability (Waldron et al 2006). Males showed significantly larger home ranges than females seasonally. This is due to the fact that male movements are significantly larger than females. Gravid females restrict their movement because they primarily focused on selecting sites to lay eggs while males were on the lookout for mates.

Habitat use is also significantly influenced by availability of prey. In case of *C. horridus* difference in habitat selection during the foraging season reflected the dietary partitioning within the two sexes. These microhabitat sites were selected on a temporal basis, with animals seen resting in one site for a week, only to move out to forage and returning back to these sites (Daltry et al 1998). In vipers, which are thought to be sluggish and are ambush specimen was from the Sunderbans, as described by Cantor in 1836, '*in a jungle not far from Calcutta*'.

Plate 1. The study animal: king cobra *(Ophiophagus hannah)*

1.1.2. Identification

The king cobra is a monotypic species belonging to the family '*Elapidae*', which also includes other venomous snakes such as kraits, cobras, coral snakes etc.; with only one species of its genus *Ophiophagus*. *Ophiophagus hannah* can be identified by other cobras by the presence large head scales known as **'occipitals'**, which are behind the nine-scale arrangement seen in most of the elapids such as cobras, kraits and coral snakes. The hood of king cobras also are narrow and are flattened extensions of the ribs and do not have any markings on the back as compared to other cobras; a spectacle (*Naja naja*) or a monocle (*Naja kaouthia*).

However there have been investigations whether this case is taxonomically significant, which can differ variably across its distribution. The theory can be hypothesized based on different appearances of king cobras found across the distribution within the Indian sub-continent. *Ophiophagus hannah* is now being considered as a species complex (Das 2002). King cobras are generally black to brown in color with pale yellow bands. King cobras in the Western Ghats have been observed to be much darker and faint bands as compared to individuals in other parts of its range, which have prominent thick bands. The juvenile king cobras have yellow bands and can be mistaken for banded kraits *Bungarus fasciatus*. It has two short fixed fangs a characteristic in all elapids that channels venom into the prey like hypodermic needles. The male is larger and thicker than the female and can be identified by the size of the head that is normally broad and longer in length while the female has a smaller and narrower head and is relatively smaller in length.

1.1.3. Taxonomic Characters: Scalation

Dorsal scales: midbody 15 rows; Ventral scales: Males 235-250, females 239-265; Tail: Subcaudal scales single or paired in each row, 83-96 in males and 77-98 in females (Whitaker and Captain, 2004).

1.1.4. Biology

a. Diet

King Cobra diet constitutes of other snakes and occasional juvenile monitor lizards. In captive conditions, king cobras have been fed with dead rats dipped in 'snake soup'. King cobras have been observed feeding on rat snakes *Ptyas mucosa*, spectacled cobras *Naja naja*, Malabar pit viper *Trimeresurus malabaricus* and hump nosed pit viper *Hypnale hypnale* (Bhaisare et al 2010). They have also been observed feeding on banded kraits *Bungarus fasciatus*, rock python *Python molurus molurus* and reticulated python. King cobras actively forage, relying on scent and chemical cognition to locate their prey and also to track females. They are primarily diurnal, though there have been occasional observational records of king cobras being active after dark.

b. Reproduction

The female of the King cobras is the only snake in the world that builds a nest. Nest building occurs soon after the breeding season, which is normally between the months of March to April as observed in the population in the Western Ghats, India. The female builds the nest, before she lays the eggs, and remains with them. The clutch size ranges between 20-30 eggs. The nest chamber is designed in a fashion that it stays dry and the temperature normally is around 28 °-30°C (82° F). The nest is a mound of leaf litter and other dead vegetation, which acts as a substrate. The female uses her body, coils around the leaf litter and drags the substrate to one spot. Little information is available on nest sites from other parts of the distribution range of king cobras. However, nest building has been observed in August in populations occurring in the Shivaliks and Western Himalayas.

1.1.5. Distribution

The king cobra is a rare but widely distributed species (Günther, 1864; David and Vogel 1996, Bashir et al 2010) and occurs in South and Southeast Asia. It occurs in India, Nepal, Bhutan, Myanmar and parts of Southeast Asia (David and Vogel 1996; Selich and Kestle 2002; Vogel 2006). In India it occurs in the Western Ghats, foothills of the Shivaliks and Terai regions of the state of Uttarakhand and Uttar Pradesh (needs confirmation), in the Eastern Ghats in the states of Andhra Pradesh, in littoral forests of Orissa and West Bengal and the Andaman and Nicobar Islands; Sikkim and Northeast states of Assam, Meghalaya, Arunachal Pradesh, Nagaland, Tripura and Manipur (Günther, 1864; Aagard 1924; Smith 1943; Daniel 2002; Das 2002; Whitaker and Captain, 2004; Bashir et al 2010; Chettri et al 2010). Throughout its range it occurs in a wide variety of habitats ranging from grasslands, mangrove swamps, and broad-leaved forests to rainforests.

Plate.2. The current distribution of king cobra (*Ophiophagus hannah*), IUCN

1.1.6. People and the King Cobra

King cobras are feared and persecuted in many parts of its range except in parts of Western Ghats, where people revere the king cobra. This is evident by the presence of many stone idols of the snake in and around many villages scattered within the Southern Western Ghats. In Patia village in Orissa in Eastern India, snake charmers often catch wild king cobras and use them for display. In spite of its popularity and enigma, it is not a popular exhibit in many zoos of the country except a few in the state of Tamil Nadu, Karnataka, Goa and Maharashtra in the Western Ghats region and Andhra Pradesh and Orissa in the Eastern Ghats region. In the northeast, king cobras are killed instantly on sight and locals show no tolerance towards the large ophidian species.

There have been, however various instances of king cobras entering people's houses for refuge, in search of mate or in search of a suitable nest site. In Agumbe within the study area, these stray individuals are rescued by the Agumbe Rainforest Research Station team under the supervision of the forest department authorities and released back into a suitable site.

1.1.7. Conservation and Protection status

It is protected by the Government of India as a schedule II species of the Wildlife Protection Act (1972) and is listed as in Appendix II of the Convention on International Trade in Endangered Species (CITES). International Union for Conservation of Nature (IUCN) states it as a 'least concern' species.

2. Justification of the study and objectives

There is limited literature on *Ophiophagus hannah* which mainly include occurrence records and ad libidum observations mostly in captivity but few in the wild. The King Cobra Telemetry Project in Western Ghats, India is probably the only study of its kind to have been initiated to understand the ecology of this charismatic but lesser known species. The king cobra is one of the most elusive species, with very few sightings, despite being a large bodied reptile. The recent findings of the snake's newer distribution in terms of elevation and occurrence in a new habitat type leaves scope to study about the habitat ecology and preference of this species. The king cobra is a top-carnivore, strongly influencing the composition of other snake populations therein being ophiophagus. Daily/Seasonal eco-geographical requirements of king cobra and its multiple scale- space use are relatively unknown.

The king cobra can be used as a flagship species and with the Western Ghats, being under constant threat of fragmentation and deforestation; the data generated can be a valuable tool in assisting the conservation of the remaining forested habitat of the king cobra. Adverse effects of development projects or climate change on the preferred eco-geographical range of king cobra cannot be confronted without such knowledge.

Thus this study was designed in collaboration with the ongoing study keeping the following objectives in mind.

1. **To estimate home range, habitat use and movement patterns of king cobra**

   The research questions are:

- What is the home range size of king cobras in the study area?
- How are different habitat types used at a home range scale?
- How do micro environmental variables such as temperature, humidity and wind influences movement patterns?

2. **To investigate microhabitat factors influencing site selection (retreat sites and nest sites)**

The research questions are:

- Do king cobras select certain microhabitat conditions for retreat sites?
- Which habitat variables influences nest site selection?

3. **To describe and understand distribution (occurrence) patterns at the landscape matrix**

The research question is:

- What are the large scale habitat factors driving such occurrence patterns?

3. Study Area:

3.1. Location:

The study was conducted in Agumbe (13.5087°N 75.0959°E), a village located in the Shimoga district in Karnataka, India. It occurs in the Central Western Ghats Region of Western India. The elevation of Agumbe is 716 m above sea level.

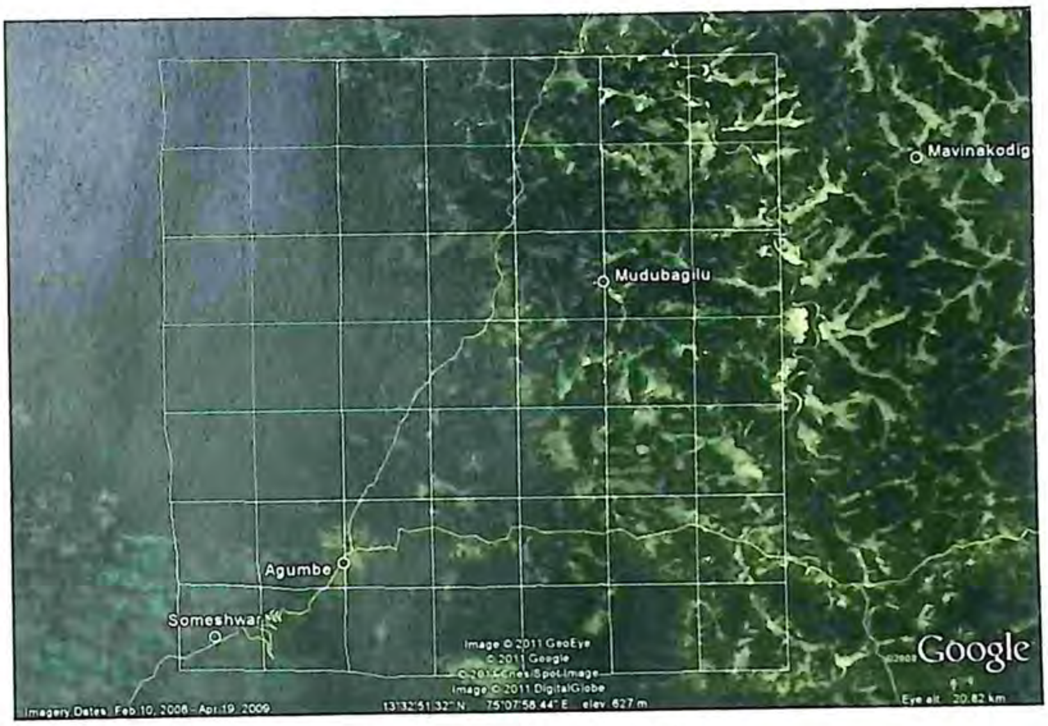

Plate 3. Google Earth image of location of intensive study area

The Agumbe reserve forest (53.4 sq.km) is part of the Kudremukh sub cluster (6 of 7 sub cluster), an initiative for enlisting India's Natural Heritage Property along with Kudremukh National Park (600 sq.km), Someshwara Wildlife Sanctuary (88.4 sq.km), Someshwara Reserve Forest (112.9 sq.km) and Balahalli Reserve Forest (32.4 sq.km) comprising an area of more than 800 sq.km. (Mathur UNESCO-ASI National Seminar 2008)

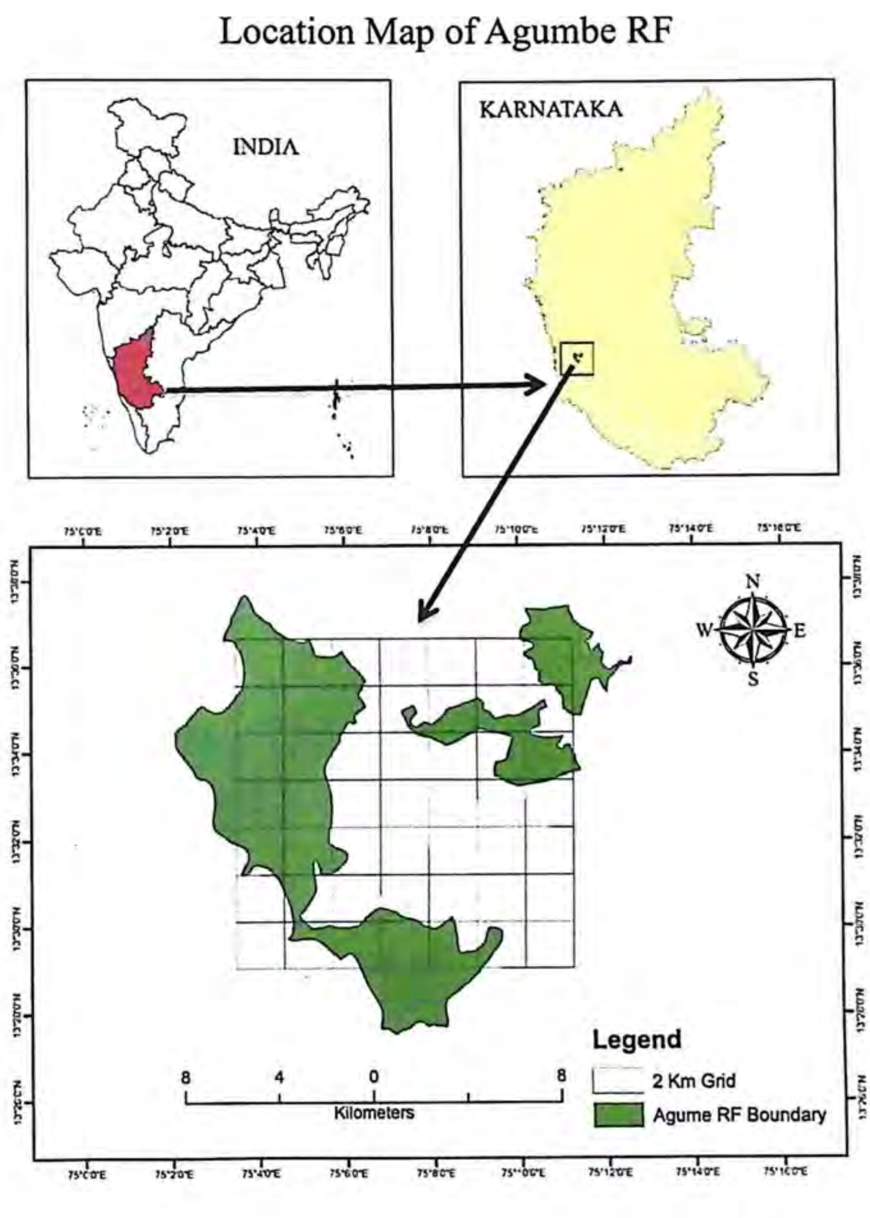

Plate 4. Location of intensive study area

3.2. Climate and Rainfall

The climate is moist tropical during the monsoon. However it has colder regimes during winter and hotter regimes during summer. Agumbe receives the second highest annual rainfall in India, after Cherrapunji in Meghalaya. The relative humidity level is as high as 90% and the mean temperatures are within the range of 10-35°C. The rainfall regimes are higher in the months of June, July and August with a range temperature of 15-25°C but humidity levels are higher in the monsoon (>95%).

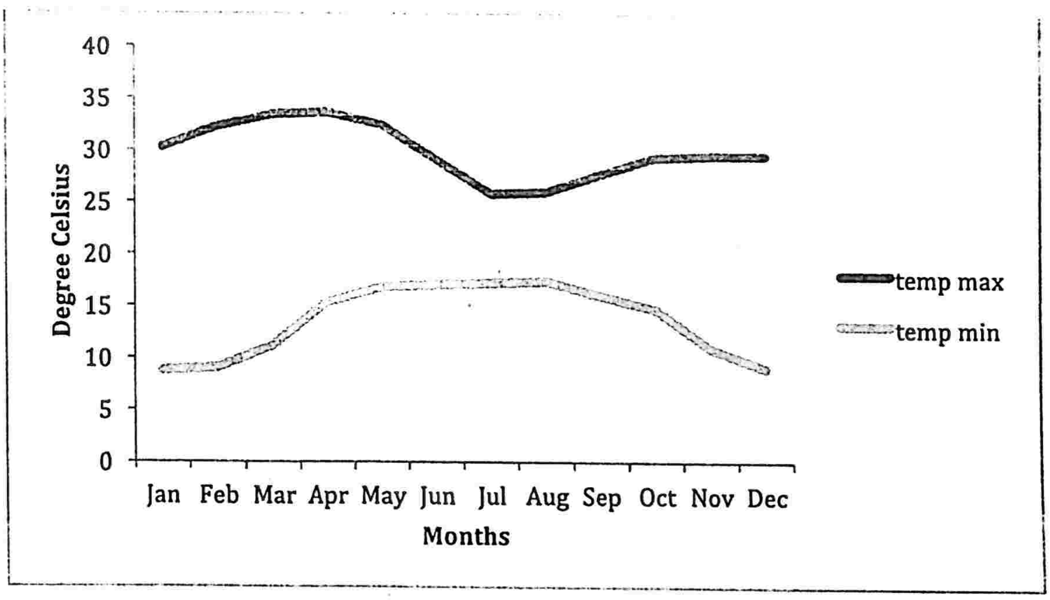

Figure 1.1. Graph showing minimum and maximum temperatures in Agumbe, Karnataka for all months from the years 1961-1980

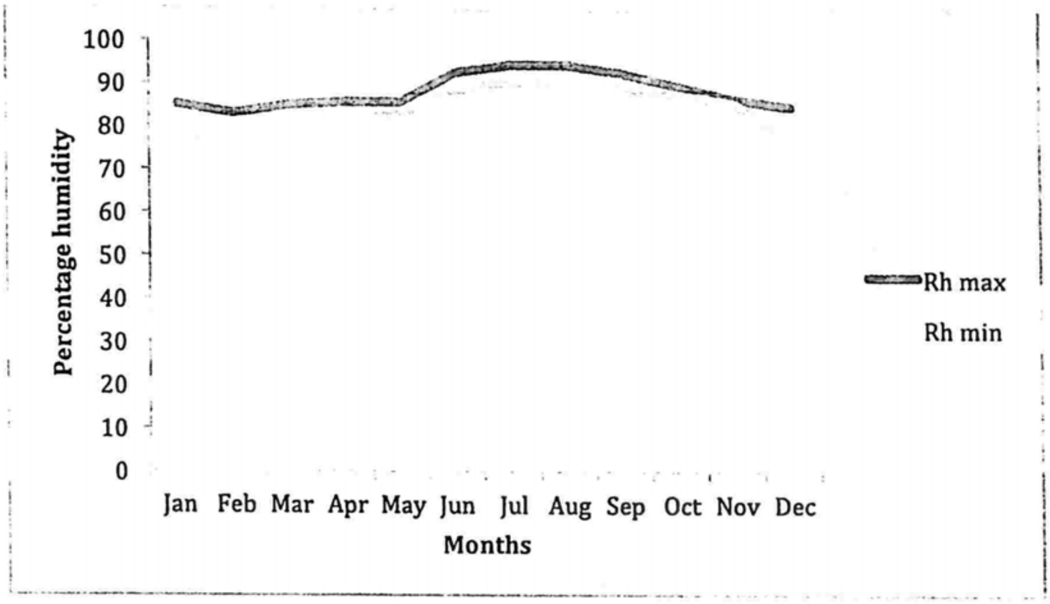

Figure 1.2. Graph showing minimum and maximum relative humidity in Agumbe, Karnataka for all months from the years 1961-1980

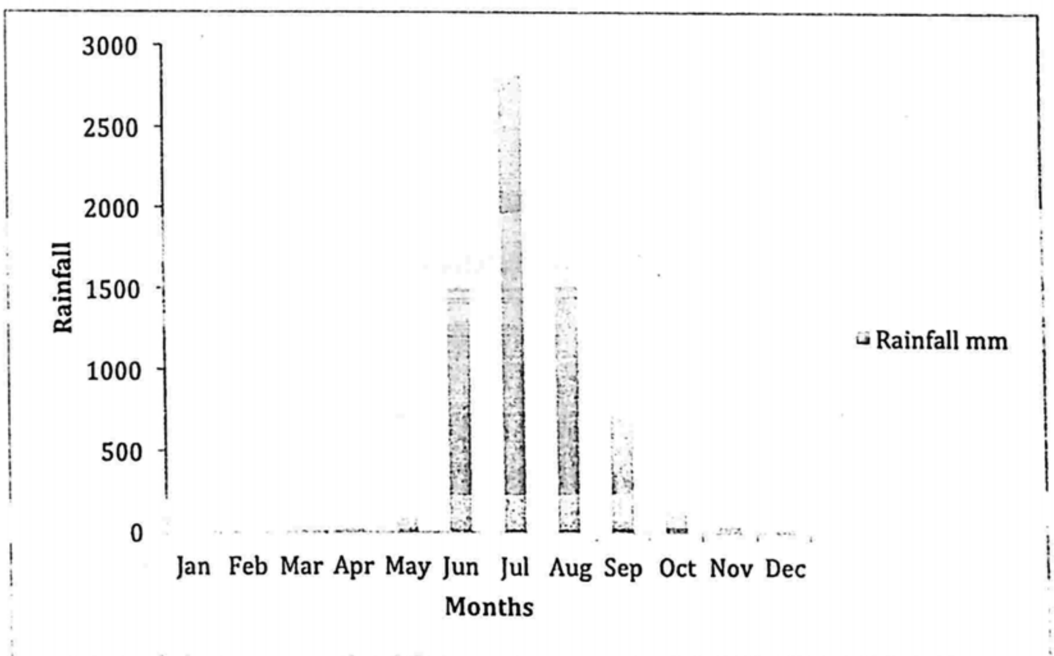

Figure 1.3. Graph showing rainfall in Agumbe, Karnataka for all months from the years 1961-1980

3.3. Vegetation and Landscape Matrix:

The forests are classified as West Coast Tropical Evergreen forest (1/A-C/4) by Champion & Seth (1968). The forests contain dominant plant types such as *Dipterocarpus indicus- Diospyros candolleana*; *Humboldtia brunonis, Artocarpus hirsutus* (Pascal 1988). However, many areas around the reserve forest have been converted in to Acacia *Acacia auriculiformis* plantation, Areca nut *Areca catechu* plantation, Banana plantation and paddy field, where the primary production is of wheat and rice. Thus, the entire landscape makes a mosaic of various habitat types viz. forest, paddy field and plantation.

3.4. Biodiversity

The Western Ghats is one of the biodiversity hotspots of the world (Critical Ecosystems Fund 2007). Within its entire range of 1,80,000 sq.km covering the states of Gujarat, Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu more than 4000 sp. of flowering plants, 650 sp. of trees occur here; faunal species include around 280 spp of fishes, 128 and more spp of amphibians, 157 spp of reptiles, 508 spp of birds and 127 spp of mammals. The invertebrate diversity includes around 337 spp of butterflies and 200 spp of spiders (Critical Ecosystems Fund 2007).

In terms of floristic value in the study area, Agumbe has the Medicinal Plants Conservation Area (MPCA) is an area created for the conservation of Medicinal Plants (Prabhakaran 2003). This area is located at an altitude of 600 to 700 meters above Sea level. Some of the species of plants found here are *Garcinia*, *Myristica*, *Litsea*, *Diospyros*, *Holigarna*, *Eugenia* and *Ficus*. An organization called the *Foundation for Revitalization of Local Health Traditions (FRLHT)* conducted a survey in the MPCA and identified 371 plant species of which 182 were medicinal. Some of the species of plants that are found here are RLs (Red-listed and hence endangered) such as *Adenia hondala, Celastrus paniculatus, Garcinia gummi-gutta, Myristica dactyloides, Persea* *macrantha, and Vateria indica. Salacia oblonga* is another medicinal plant endemic to the Western Ghats and Sri Lanka but found only in this MPCA (Prabhakaran 2003), faunal assemblages include with over 33 species belonging to 25 genera and 16 families of herpetofauna (Ganesh and Mouli 2006), 30 spp of birds (Shyamal and Rajkumar 1995) and around 10 species of mammals.

4. Methods:

4.1. Reconnaissance Survey

A preliminary reconnaissance survey was conducted in the chosen field area to choose the intensive study area. This area (13.5087°N 75.0959°E) has been surveyed regularly in the past by the ongoing King Cobra Telemetry Project (KCTP) of the Agumbe Rainforest Research Station and the University of Arizona. The project has been conducting radio telemetry studies on the king cobra and has generated presence locations since the initiation of the study in March 2008. This enabled collation of historical information with the present study for more reliable analysis of factors influencing space use by this rare species.

4.2 Geomatics

4.2.1. Remote Sensing and GIS:

Global Positioning System

The location points were taken in the Universal Transverse Mercator format. These points were recorded using Garmin GPS 72 H and eTrex Vista.

Google Earth

The software Google Earth was used to choose boundaries of the present study including the Intensive Study Area (ISA) that included the home ranges of the radio tagged snakes F1, M1, M2 and M4 and also rescue sites of king cobras. Google Earth was also used for geo referencing the area and used to plot sampled points within the grids.

Land Use Land Cover (LULC) Map

The land use land cover map at 1:250000 scale was derived from Indian Remote Sensing Satellite (IRS 1D) Linear Imaging Self-scanning Sensor (LISS) III image by degrading the spatial resolution from 23.5 meters to 62.5 meters. The LISS III data for the year 2005 was classified using supervised classification scheme to arrive at the land use land cover (LULC) map. This map was later used to compute habitat use by radio tagged king cobras.

Field methods for the first objective: Factors influencing movement patterns and habitat use

4.2.2. Radio Telemetry:

Data were collected from the ongoing king cobra telemetry project (KCTP) that was initiated in March 2008 and were used for presence location determination. During the entire duration of the project from March 2008 till now, 5 snakes (ID: F1, M1, M2, M3 and M4) have been tagged and data collected from all these individuals. These snakes have being tracked by using a digital receiver with a Yagi antenna. The transmitter (make- Holohil systems; model AI-2T weight 24 grams) and was used for the snakes (F1 and M2- Frequency 148.720 MHz, serial no 121220; M1- serial no 128075, Frequency 148.243; M3- Frequency 148.100, serial no 143409; M4- Frequency 150.782 MHz, serial no 148452). The transmitters were surgically inserted into the coelomic cavity (Weatherhead and Anderka, 1984). By the time, this study was initiated in December 2010 only one transmitter of snake ID OPHA M4 was functional and signaling.

The present study largely focused on the radio tagged king cobra ID M4, which is a male (weighing 6 kilograms, total length 346 cm, tail length 57.2 cm) and is being tracked on a regular basis from December 2009 till now. The snake was caught again for refitting the transmitter in January 10 2011 during the duration of the present study and was tracked till April 2011. The parameters recorded were spatial variables like location in Universal Transverse Mercator (UTM) (North and East), accuracy, direction, moved; physiological variable like Beats Per Minute (BPM); physical variables like wind, cloud, ambient temperature (TA) and relative humidity (RH), temperature (TCM- one cm above the ground), rain (yes or no), weather (sunny or cloudy); visible (yes or no) and behavior (listed resting, foraging, moving and ecdysis if observed). The habitat variables measured were thermal (shade, dappled or open); distance from nearest cover type and a location where the animal has remained for a night was selected for recording habitat variables which were classified as microhabitat (in which variables were recorded within 5 meter radius of location), mesohabitat (within 20 meter radius) and macrohabitat and the variables were: canopy cover (ground (<1m), under-story (<3m), mid-story (<10m) and over-story (>10m)); ground characteristics like bare ground, rock, leaf litter, tree, shrub, grass, dead vegetation (all in percentages) and litter depth (in inches). This was same for mesohabitat variables but was collected from within 20 m radius. The macrohabitat variables included canopy cover using densitometer (CANOPY), distance to nearest slope (DSLOPE), distance to nearest stream (DSTREAM), distance to nearest clearing (DCLEAR), distance to nearest log (DLOG), Dominant vegetation types, Forest type (Open, Moderate and Dense), Description and distinctive features of the site. Data was collected from 0800 hours to 1600 hours depending upon the activity of the animal. If the animal were moving then it would be followed and monitored until it stops moving and selects a retreat site for which the above mentioned habitat variables were recorded.

Field methods for the second objective: Factors influencing retreat and nest site selection

4.3.1. Grid Sampling:

a) Retreat sites

The retreat sites were chosen where the radio tagged animal(s) had seen resting for the whole night. All these sites were within the boundaries of the grids of the intensive study area. Additional retreat sites located during the present study from December 2010 to April 2011 were added to the existing database of retreat sites. At each of the retreat site thermal covariates like ambient temperature (TA) (Schwaner 1989; Row and Demers 2005) Relative humidity (RH) (Daltry et al 1998) and canopy cover using spherical densiometer; habitat covariates were measured viz. habitat type, % shrub cover (Madsen 1984;

Weatherhead et al 1985), % dead vegetation and leaf litter depth (using 15 cm ruler); land characteristics like burrows (BURR), fallen logs (F_LOG), distance from nearest water source (DIST_STREAM); distance to nearest burrow (DIST_BURR), distance to nearest fallen log (DIST_FLOG) and distance to nearest rock (DIST_ROCK) were measured using a measuring tape. Random locations within 50 m radius of presence locations were also collected to compare between locations and site usage (Pringle et al 2003).

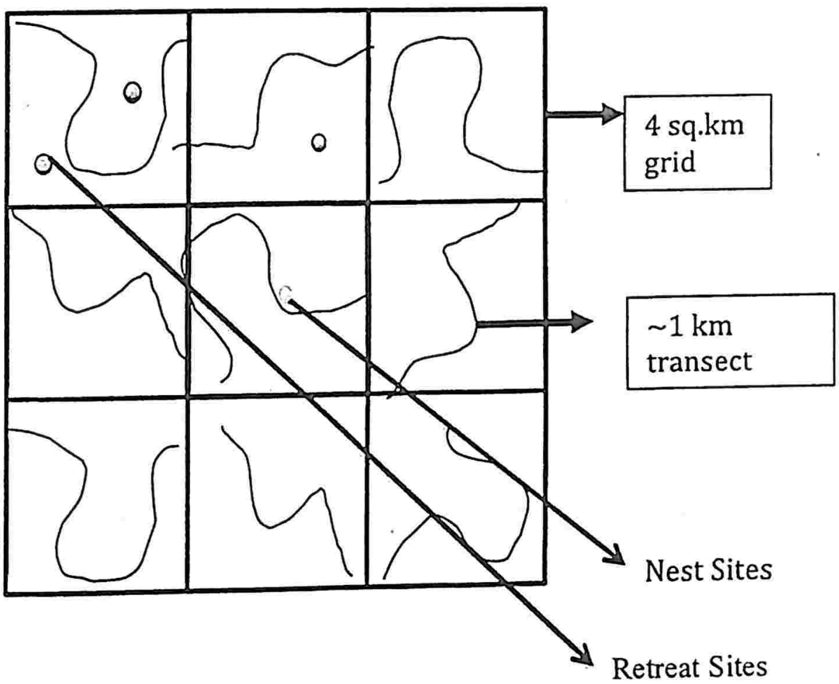

Figure 2.1. Grids with retreat sites recorded during the King Cobra Telemetry Project and Prey density Transect design within the 4 sq.km grids within the ISA

b) For nest sites

The study duration from December 2010 to April 2011 coincided with the breeding season of king cobras i.e. during March to late April. Since king cobra females are the only species of snakes in the world that make a nest, sampling for habitat covariates of nest site was also carried out. Habitat sampling was conducted at 13 nest sites locations and four random locations at 50 m distances from each nest site in four directions. The location of nest sites and paired random sites were recorded on the GPS and habitat covariates such as habitat type (HAB_TYPE), location, shrub cover (SC), dead vegetation (DV), canopy cover (CC) and slope (Gentle or Steep) were recorded.

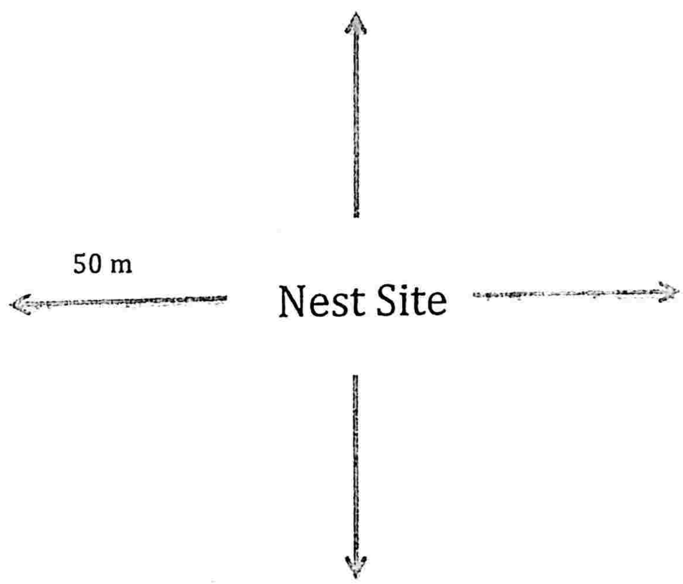

Figure 2.2. Random location sampling from a king cobra nest site to test selection of sites. In all 4 directions, similar variables were recorded to test preference of a female king cobra to a particular site for nest building.

c) Prey Density

The entire landscape matrix was stratified into grids of 4 sq. km grids. To sample prey snake species in the grid, time constrained transects of length 1 km were carried out (Schwaner T.D. 1991). Sampling duration started from 0900 hours, as the snakes were likely to come out to bask thereby increasing detection probability. The time slot was divided into 2 hours time-sessions (0900-1100 hours; 1200-1400 hours; 1500-1700 hours). Sampling was carried out between time constraints of two hours within each grid of my study area, twice in each grid. In each time-session, observer will have to carry out visual encounter surveys along transect of ~1 km to measure abundance of prey snakes. A double observer sampling method should be used for detection correction. Fixed width or belt transects of 20m wide on both sides is better to estimate an approximate index of abundance of prey species. Sampling was carried out only for two months in two different seasons during the study period to predict patterns of detection in snakes with temperature as an influencing factor (Hebrard J. J and H.R Mushinksy 1978). The variables to be recorded on sighting an animal are: date, place, time, location, start time and end time, observers, length of transect, number of replicates, species of prey sighted, distance (m) (from the observer), habitat type, and cluster size (number of animal(s) sighted).

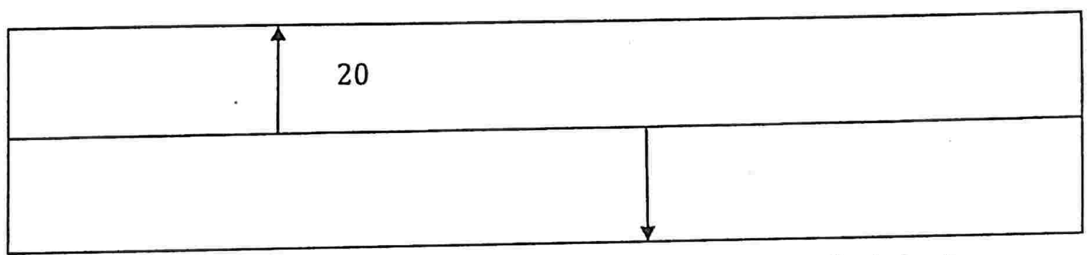

Figure 2.3. Representation of fixed width transects for ophidian prey density walks during the study in Agumbe, Karnataka during December 2010 and March 2011.

Field Methods for third objective: Factors influencing distribution patterns

Within the intensive study area and the study area matrix, king cobra occurrences were documented. Mostly this came out of rescue calls received by the team at ARRS. Compiling this information (compiling rescue data of five years: 2006 to 2011), including occurrences recorded during the study duration (December 2010-April 2011). The presence locations also included those collected from the radio tagged individuals and previous records from the study area landscape.

Presence locations were generated using this secondary data, which was then put on a GIS domain to construct species distribution models.

5. Data Analysis

5.1. Analytical Methods for the first objective: Factors influencing movement pattern

Analysis was conducted at the level of individual snakes on data collected from the four-tagged individuals (snake ID: M1, M2, M4, F1) as the fifth snake ID M3 had inadequate data.

KERNEL HOME RANGE ESTIMATION

Kernel home range estimates were estimated to determine size of home ranges within the study area matrix using 95% and 50% Isopleths (Brito et al 2003, Whitaker and Shine 2003, Web and Shine 1997).

MINIMUM CONVEX POLYGON ESTIMATES

MCP ranges for the tagged four snakes were computed at 95% for home range estimates.

JACOB'S INDEX FOR HABITAT USE VS. AVAILABILITY

Habitat use vs. availability was computed using Jacob's Index 1974 (Thirgood 2009).

Index of Jacobs (1974) calculated as: Ei = (Ui -Ai)/{(Ui + Ai) - [2 * (Ui * Ai)]}

> Where U is the estimated proportional use of habitat type i and Ai is the proportion of the study area occupied by habitat type i

A generalized linear model framework (GLM- logit link and binomial error, i.e. logistic regression) where movement vs. no movement (binary response) was modeled with environmental parameters such as ambient temperature (Ta), relative humidity (RH), wind and wind direction (fcwind) and their combinations/interactions to understand movement patterns. The statistical analysis was done using R version 2.11.1. For population level inference, I computed average and unconditional Standard Errors of regression coefficients of variables across individual based models.

5.2. Analytical Methods for the second objective: Factors influencing habitat use

GLM framework was used to model retreat and nesting sites vs. the unused sites with microhabitat variables in program R version 2.11.1.

Firstly, to investigate factors influencing retreat site selection, presence/absence (binary response) with habitat data collected from 262 points (210 presence and 52 absence) was modeled using logistic regression (Crawley 2007). Absence locations were obtained from the systematically sampled habitat points that did not have presence records. Habitat variables were checked for correlations between the by running a Spearman Correlation test and out of the highly correlated variable pair, the ecologically less meaningful and redundant ones were removed the model. A full logistic regression model with linear predictors (microhabitat variables) was constructed and then used backward selection AIC (Akaike Information Criterion) to obtain a reduced 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.

Secondly to investigate the influence of microhabitat variables on nest site selection, data from 13 nest sites was used along with 52 paired random sites. A similar logistic regression model was run against nest vs. random sites with habitat variables, such as shrub cover (SC), leaf litter (LL), canopy cover (CC), leaf litter depth (LL_DEP) and slope (Gentle or Flat). Habitat variables were checked for correlations by running a Spearman Correlation test and out of the highly correlated variable pair, the ecologically les meaningful and redundant ones were removed. A full logistic regression model was constructed with linear predictors (microhabitat variables) and then used backward selection using AIC (Akaike Information Criterion) to obtain a reduced model.

Computing prey density

The statistical analysis was done using Microsoft Excel 2011 and Distance 6.

5.3. Analytical methods for third objective:

Species distribution models were used to predict distribution of *Ophiophagus hannah* within the study area landscape matrix. The software MaxEnt was used for this distribution modeling and the environmental layers were taken from bioclim data (www.worldclim.org/bioclim). The following environmental layers were used for the analysis:

The other layers that were used were the land use land cover map (LULC) on which the presence locations (n= 1040) were plotted.

A simple Pearson's correlation test was run to check for correlations. This was to have easy interpretations of variable response on graphs, which else can be hard to interpret if there are strongly correlated variables, as the model may depend on the correlations in ways that are not evident in the curves.

Table 5.1. Codes for bioclimatic variables obtained from bioclim used to influence of the following variables to king cobra distribution in Agumbe and the adjoining areas

Code	Variable
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Table 5.2. Vegetation classes in the LULC map: a (LISS) III image derived from IRS 1D at a 1:250000 scale by degrading spatial resolution from 23.5 meters to 62.5 meters. This LISS III data year 2006 was classified using supervised classification scheme to arrive at the following classes listed in the table

Value	Class name
1	Build up
2	Kharif crop
3	Rabi crop
4	Zaid crop (summer)
5	Double / triple crop
6	Current fallow
7	Plantation/orchard
8	Evergreen forest
9	Deciduous forest
10	Scrub/Deg. forest
11	Littoral swamp
12	Grassland
13	Other wasteland
14	Gullied
15	Scrubland
16	Water bodies

6. Results

6.1. Results for the first objective- Factors influencing movement pattern

A univariate logistic regression was run to investigate which particular factor/variable influences movement pattern of the four radio tagged king cobras.

A correlation analysis was run to check for correlated variables. Correlation was seen in some variable (wind and fcwind) but these variables were still used, as they did not significantly influence Beta estimates.

Wind direction (W-E), Temperature (TA) (20-35°C) and Relative humidity (RH) (50-90%) have a significant influence on movement pattern of king cobra, the Beta estimates for TA are 0.1 while for Rh is -1.34 and fcwind, which is a categorical dataset showed the lowest AIC value.

All models shown in these results have been selected based on the lowest AIC value.

a. The results for individual ID M1.

A bivariate model was run using these variables significant enough from the initial univariate regression to make additive models. The model with wind direction (fcwind) and ambient temperature TA make a decent model with the lowest AIC values.

The bivariate model: [(fcwind + TA) model chosen after AIC values]

Table 6.2.1. GLM with environmental variables for snake ID M1

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-4.75281	1.09439	-4.343	1.41e-05 ***
E-W	-1.35356	0.62300	-2.173	0.02981 *
N-S	0.42964	0.42007	1.023	0.30641
NE-SW	-0.90456	1.06908	-0.846	0.39749
NW-SE	0.68122	0.74628	0.913	0.36134
S-N	-0.69278	0.55493	-1.248	0.21188
SE-NW	-16.41461	1309.93560	-0.013	0.99000
SW-NE	-16.17516	628.45952	-0.026	0.97947
W-E	-1.06418	0.39276	-2.709	0.00674 **
TA	0.12720	0.03986	3.191	0.00142 **

Null deviance: 704.30 on 742 degrees of freedom

Residual deviance: 658.79 on 733 degrees of freedom

AIC: 678.79

b. The results for individual M2

The best-fit model:

Table 6.2.2. GLM with environmental variables for snake ID M2

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	9.0605	4.0073	2.261	0.02376 *
E-W	-17.6999	1328.7198	-0.013	0.98937
N-S	-18.1736	4665.9467	-0.004	0.99689
NE-SW	-16.9675	7603.4790	-0.002	0.99822
NW-SE	-17.1252	6155.8215	-0.003	0.99778
S-N	0.9189	1.2606	0.729	0.46604
SE-NW	21.6355	10754.0129	0.002	0.99839
W-E	-17.7801	1431.1250	-0.012	0.99009
RH	-2.4191	2.1495	-1.125	0.26040
Ta	-0.3274	0.1033	-3.169	0.00153 **

Null deviance: 202.38 on 336 degrees of freedom

Residual deviance: 156.51 on 327 degrees of freedom

AIC: 176.51

c. The results for individual M4:

The best fitting full model:

Table 6.2.3. GLM with environmental variables for ID M4

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-8.35658	1.58004	-5.289	1.23e-07 ***
Rh	5.95259	0.84280	7.063	1.63e-12 ***
E-W	-1.71961	0.37537	-4.581	4.63e-06 ***
N-S	-1.64821	0.47277	-3.486	0.000490 ***
NE-SW	-1.49781	0.42344	-3.537	0.000404 ***
NW-SE	-0.32380	0.43684	-0.741	0.458543
S-N	-0.11337	0.36934	-0.307	0.758889
SE-NW	-1.02622	0.35992	-2.851	0.004355 **
SW-NE	-1.31816	0.29931	-4.404	1.06e-05 ***
W-E	-0.73983	0.25980	-2.848	0.004404 **
Ta	0.13078	0.04101	3.189	0.001426 **

Null deviance: 1102.39 on 1268 degrees of freedom

Residual deviance: 928.32 on 1258 degrees of freedom

AIC: 950.32

d. The results for individual ID F1

The best fitting model:

Table 6.2.4. GLM with environmental variables for snake ID F1

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	9.066e+00	4.028e+00	2.251	0.02440 *
Ta	-3.276e-01	1.042e-01	-3.145	0.00166 **
RH	-2.421e+00	2.155e+00	-1.124	0.26121
Wind	3.357e-03	2.458e-01	0.014	0.98911
E-W	-1.771e+01	1.329e+03	-0.013	0.98937
N-S	-1.818e+01	4.666e+03	-0.004	0.99689
NE-SW	-1.699e+01	7.602e+03	-0.002	0.99822
NW-SE	-1.714e+01	6.157e+03	-0.003	0.99778
S-N	9.128e-01	1.337e+00	0.683	0.49482
SE-NW	2.163e+01	1.075e+04	0.002	0.99839
W-E	-1.779e+01	1.431e+03	-0.012	0.99008

Null deviance: 202.38 on 336 degrees of freedom
Residual deviance: 156.51 on 326 degrees of freedom
AIC: 178.51

An average of regression coefficients (β estimates) and standard errors (conditional and unconditional) were computed to test influences of values at the population level. Unconditional standard error was computed by:

STD=√(variable)^2(CV(variable1)^2+CV(variable2)^2+CV(variable3)^2+CV(variable)^2

The β coefficients with the standard errors after taking the average are:

Table 6.2.5. The β coefficients with the standard errors at a population level for king cobras

Variables	β coefficients
TA	7.7e10-1 ± 0.0545
RH	1.25 ± 1.14
Wind	-1.05e10-1 ± 0.133
E-W	-4.77 ±3.31e10+2
N-S	-4.57 ±1.6e10+3
NE-SW	-4.517±1.9e10+3
NW-SE	-3.984±1.5e10+3
S-N	0.21±0.42
SE-NW	-5.36±-0.54
SW-NE	1.19±2.6e10+3
W-E	-4.69±3.5e10+2

Summary of results out of model selection:

The approach of this model averaging was to first check the influence of any particular variable based on its AIC value. This univariate approach led to a flexibility of choosing models with variables that would be highly significant. These variables were chosen with some ecological weightage with respect to the species concerned.

From the linear models, ambient temperature (7.7e10-1 ± 0.0545) (range of 20-35°C) is the single most influencing factor, followed by relative humidity (1.25 ± 1.14) (range 70-90%).

Body temperature of snakes and ambient temperature:

The body temperature of the snakes was collected during radio telemetry through the transmitter, which has a thermal sensor. BPM (beats per minute) were recorded at hourly fixes and through a conversion factor changed it into body temperature. The following graphs show the relationship of body temperatures with ambient temperatures, but seem to show no strong variation amidst body temperature with the surrounding temperature. They are able to maintain a suitable Tb, which is constant between 30-34°C.

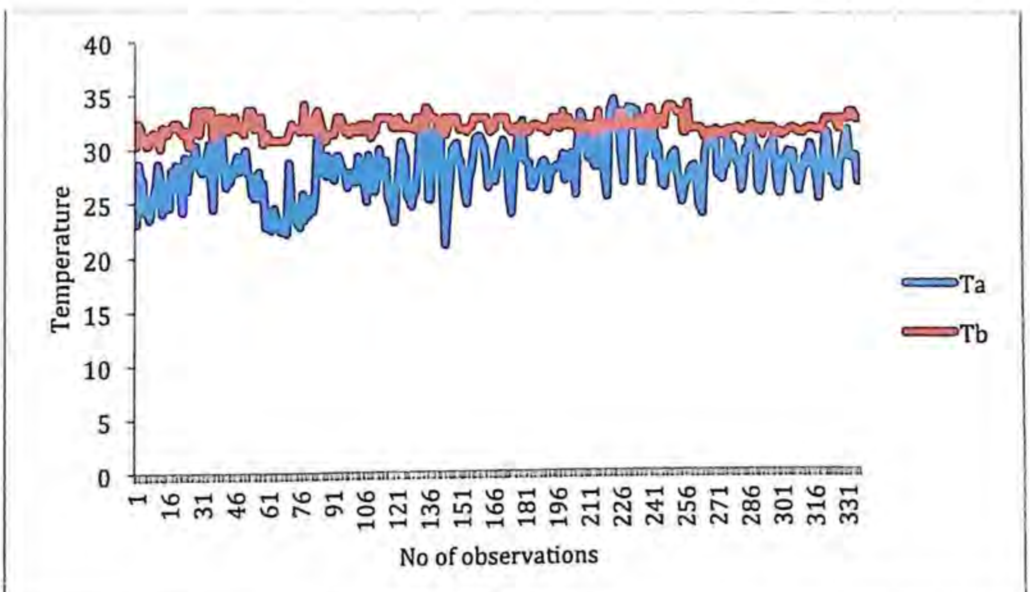

Figure 3.1. Line graph showing relationship of body temperature (Tb) and Ambient temperature (Ta) for snake ID OPHA F1 during March 2008- April 2008 in Agumbe during the KCTP

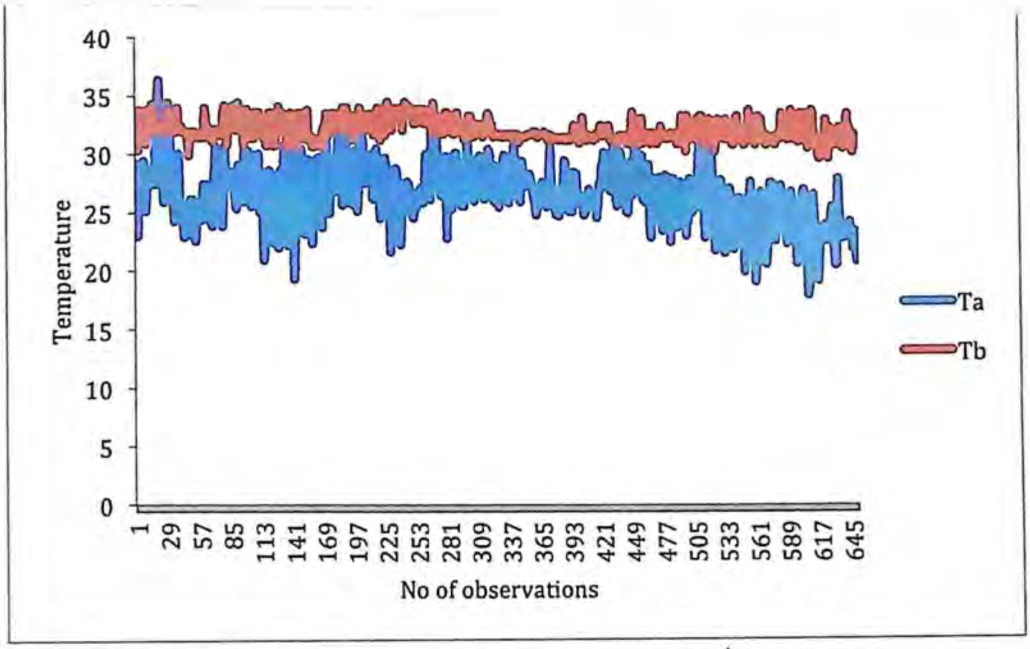

Figure 3.2. Line graph showing relationship of body temperature (Tb) and Ambient temperature (Ta) for snake ID OPHA M1 from March 2008- April 2008 in Agumbe during KCTP

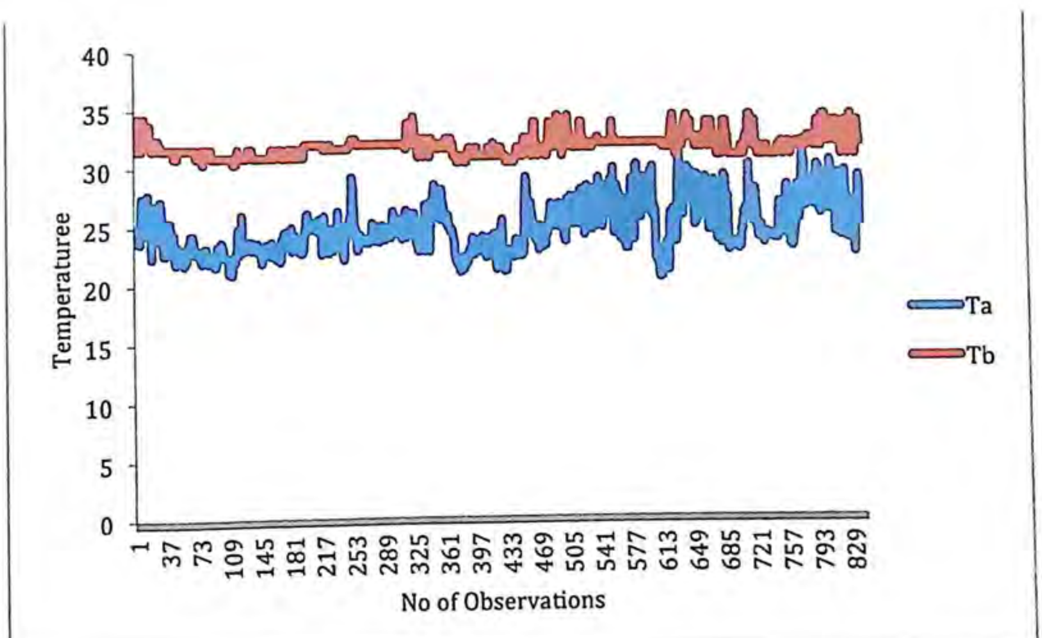

Figure 3.3. Line graph showing relationship of body temperature (Tb) and Ambient temperature (Ta) for snake ID OPHA M2 from Dec 2009 to April 2010 in Agumbe during the KCTP

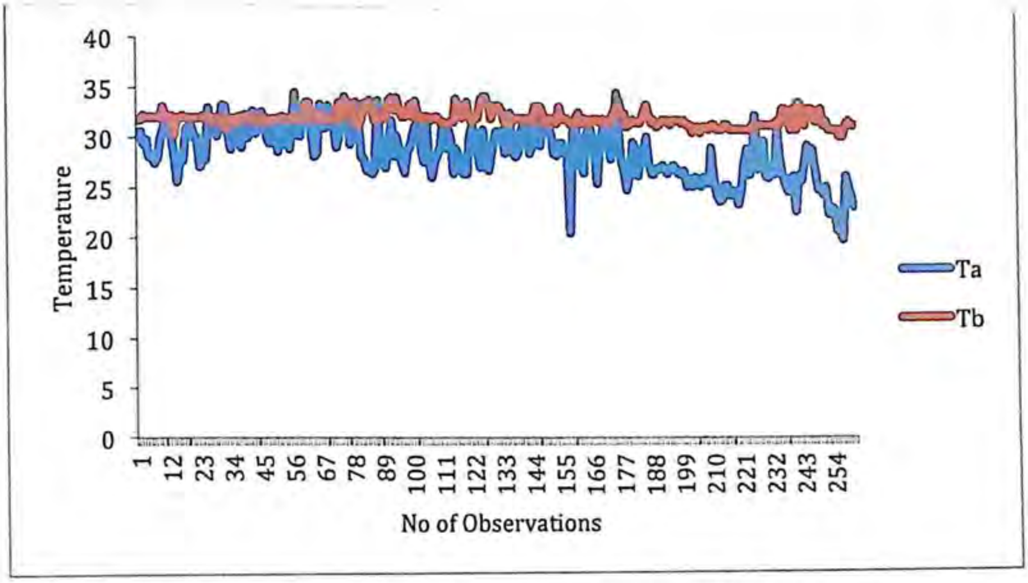

Figure 3.4. Line graph showing relationship of body temperature (Tb) and Ambient temperature (Ta) for snake ID OPHA M3 during March- April 2009 in Agumbe during the KCTP

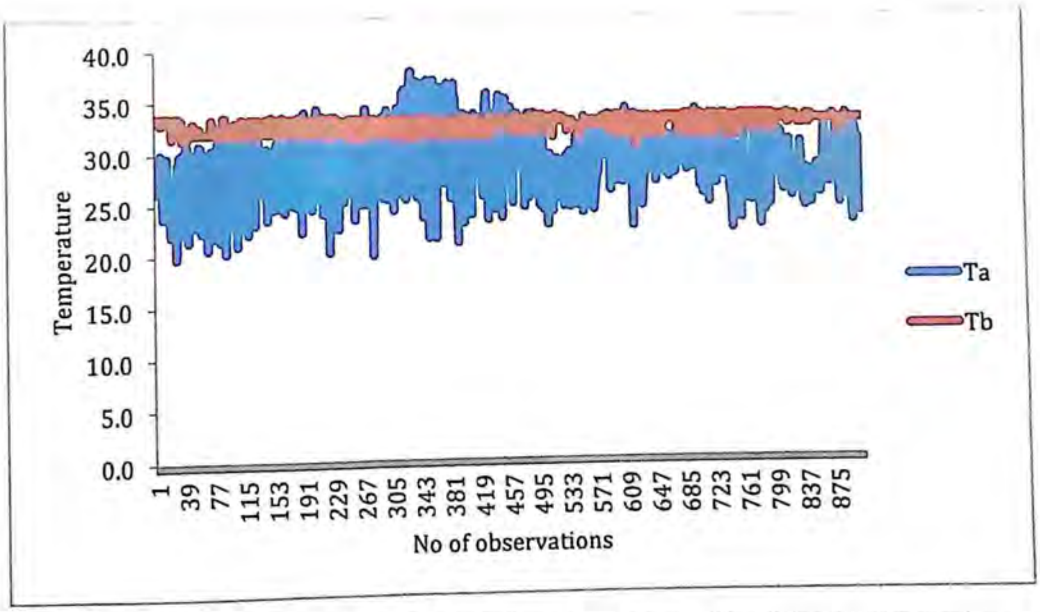

Figure 3.5. Line graph showing relationship of body temperature (Tb) and Ambient temperature (Ta) for snake ID OPHA M4 during December 2010-April 2011 in Agumbe during the KCTP

Home range and habitat use results:

Kernel estimates were computed for determining home ranges for 4 radio tagged individuals (F1, M1, M2, M4).

Table 6.3. The kernel home ranges of the 4 radio tagged king cobra estimated at 95% isopleths computed from data obtained from the KCTP

Snake ID	Kernel 95%
M1*	54 sq.km
M2	3.5 sq.km
M4	7.5 sq.km
F1	1.8 sq.km

* Relocated individual

Table 6.4. The 95 % MCP home ranges of the four radio tagged king cobras

Snake ID	MCP
F1	2.02 sq.km
M1*	90.69 sq.km
M2	15.1672 sq.km
M4	23.93 sq.km

* Relocated individual

The kernel estimates (at 95%) predict a wide margin of home ranges if M1 with the other individuals. Note however, in case of M1 whose home range is almost as large as 54 sq.km while the mean home ranges of the other individuals are around 4.6 sq.km. The reason for this wide variation is M1 was a translocated animal and it is probably the homing instinct of the individual that led it to move in such a large area. All the other individuals (M2, M4 and F1) were non-translocated individuals thus the smaller home ranges. The MCP home ranges also show a similar trend. However, the values are different as the method in which these two home range tools calculate HR is different. MCP takes in the outermost layers and makes a layer polygon while kernel estimates by adding contours around maximum cluster of points and removes areas where location points are not distributed.

The habitat use vs. availability:

Table 6.5. Habitat use vs. availability results of the four radio tagged king cobras

Rank	(U-A)/(U+A-2UA)	AVG	LCL	UCL
1	Evergreen Forest	0.19	-0.1	0.48
2	Deciduous Forest	-0.1	-0.48	0.29
3	Plantation/Orchard	-0.16	-0.83	0.51
4	Scrub/Deg Forest	-0.33	-1.09	0.43
5	Agriculture	-0.53	-1	-0.04
6	Grassland	-0.65	-1.21	-0.09
7	Water bodies	-0.72	-1.27	-0.18

The use was ranked as per significance values. The habitat use was computed using Jacob's Index (1974) to investigate preference to a particular site or random use. Evergreen forest amongst all the habitat types shows a preference of use while others are negatively correlated which either would signify as random and as lower the rank gets more they would inferred as completely non preferred areas.

6.2. Results for the second objective: Factors influencing retreat and nest site selection

a. Factors influencing retreat site selection

Pearson's correlation test was first run to deduct highly correlated variables from the model. Correlated variables beyond a value of 0.4 were removed from the models.

The GLMs were then built using uncorrelated points. The results from the generalized linear model out of 262 data points, has been computed in three separate models viz. the intercept model, the full model and the reduced model.

The reduced model (model chosen after comparing AIC values)

Table 6.6. GLM with microhabitat variables with presence as a response variable to different microhabitat variables in a retreat site during the present study

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.157e+00	4.339e-01	2.667	0.00766**
Burrow	-7.240e-01	4.303e-01	-1.682	0.09249
Edge.of.Stream	1.666e+01	1.325e+03	0.013	0.98997
Tree.Trunk	1.694e+01	1.755e+03	0.010	0.99230
Bamboo.Thicket	1.689e+01	2.509e+03	0.007	0.99463
DSTREAM	7.501e-03	3.310e-03	2.266	0.02344*
Dead Vegetation	-2.042e-02	6.712e-03	-3.043	0.00234**
F_LOG	2.327e+00	5.113e-01	4.551	5.35e-06 ***

Null deviance: 260.65 on 260 degrees of freedom

Residual deviance: 177.40 on 253 degrees of freedom

AIC: 193.40

The models were computed using microhabitat covariates, which have been hypothesized to explain some degree of influence on habitat use. This is represented using the three models shown above. The intercept model depicts the mean probability of occurrence/presences, while the full model predicts influence of all the microhabitat covariates on the probability of occurrence of king cobras in an area. I deselected certain covariates that did not show significant relationship with the response variable (i.e. Edge of Stream, Escarpment, Bund, Tree Base, Bamboo Thicket, Tree Trunk). The numbers of covariates were reduced using backward selection based on AIC values and thus the reduced model with the best AIC model (193.40) was selected. However, in the reduced model, I have retained some of these variables because a model fit without them led to higher AIC values.

The reduced model shows presence of covariate F_LOG (2.32±0.05) and DSTREAM to be positively significant with presence while dead vegetation and burrow show a very strong negative relationship.

Table 6.7. Basis of selection of reduced model (based on AIC values)

Model	-2logL*	Model df	AIC	ΔAIC
Intercept	260.65	1	262.65	65.73
Full	172.92	12	196.92	3.52
Reduced	177.4	8	193.40	0

(*AIC= -2logL+2k; -2logL= AIC-2k)

The calculated probability classification matrix computes a value of 0.88. This explains that the model correctly classifies 88% of the data points, which is statistically suitable. This would mean that the parameters have been equally represented from the dataset considering the predicted probability of occurrence is cut off at 0.6 by the model and thus could be correctly classified as absent/present.

b) Factors influencing nest site selection:

Pearson's correlation test was first run to deduct highly correlated microhabitat variables from the model. Correlated variables beyond a value of 0.4 were removed from the models.

Table: 6.8. Pearson's correlation matrix table for king cobra nest site habitat variables

	SC	CC	LL	LL_DEP
SC	1.0000000	0.2598059	-0.7738910	-0.3133563
CC	0.2598059	1.0000000	0.2278551	0.1155280
LL	-0.7738910	0.2278551	1.0000000	0.4492655
LL_DEP	-0.3133563	0.1155280	0.4492655	1.0000000

The correlation matrix showed that SC and LL had a very strong and high negative correlation. LL was not subsequently used, as LL_DEP would be a significant factor influencing site selection and was ecologically more meaningful to do so.

The final model:

Table 6.9. Final GLM for king cobra nest site with presence as a response to various microhabitat variables

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-7.34921	2.86513	-2.565	0.0103 *
SC	0.02125	0.02247	0.945	0.3445
CC	0.03880	0.03320	1.169	0.2426
LL_DEP	0.64269	0.30998	2.073	0.0381 *

Null deviance: 65.052 on 64 degrees of freedom
Residual deviance: 57.141 on 61 degrees of freedom

AIC: 65.141

The removal of the variable was significant because it also gave a model with a reduced AIC value from 66.736 to 65.141. Thus from the reduced model, LL_DEP (leaf litter depth of 3-7 inches) is a significant factor for nest site selection.

c) Results from prey density walks

Prey density walks (n=41), were carried over a span of two months December and March for two seasons viz. summer and winter. A total of 51 animals were encountered out of which Rat snake *Ptyas mucosa* was the most commonly sighted of all species (n=29). A total of 41 kilometers with two replicates were walked to compute encounter rates in a particular habitat type to correlate king cobra presences with prey availability. The encounter rates and the total prey sightings have been listed below. A total of 9 species have been recorded during the walks. However the total number of times king cobras were found encountering prey was low (n=4) thus no significant relationship could be drawn.

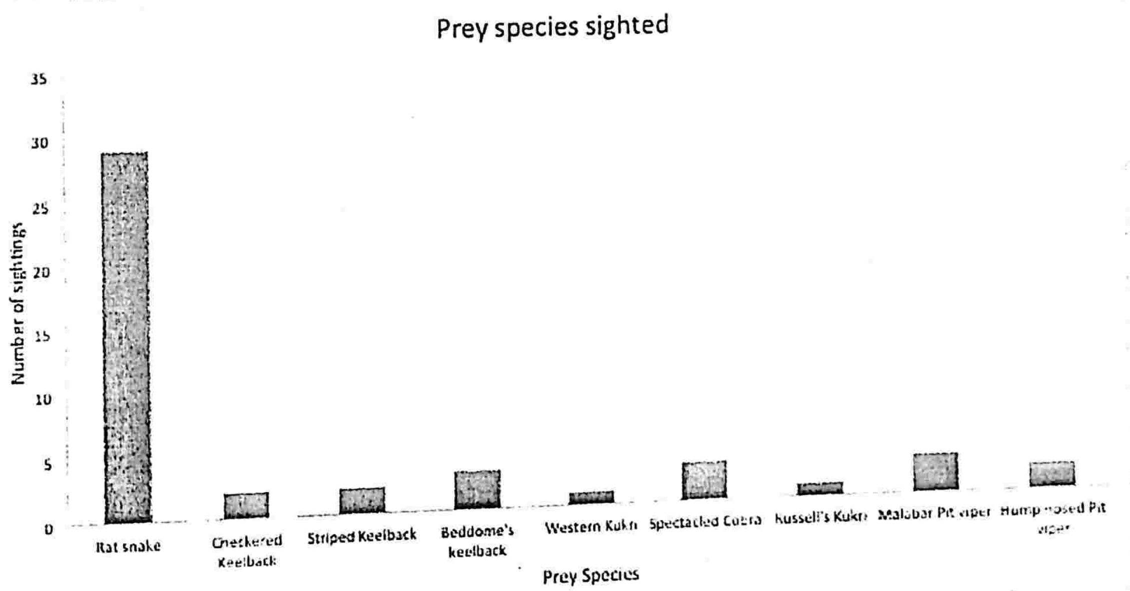

Figure 6.6. Ophidian Prey species sighted during prey density walks during the months December 2010 and March 2011 in Agumbe, Karnataka during the present study

The density estimate was done using the software Distance 6.0. However, Distance 6.0 could not be used for further analysis because density estimates from calculated from Distance software were erroneously higher (192 animals/per sq.km). The mean perpendicular distance of sighting an animal was 3.5 m, which is very likely the causative factor for an inflated density estimate. Thus data presented here are only encounter rates of the prey species.

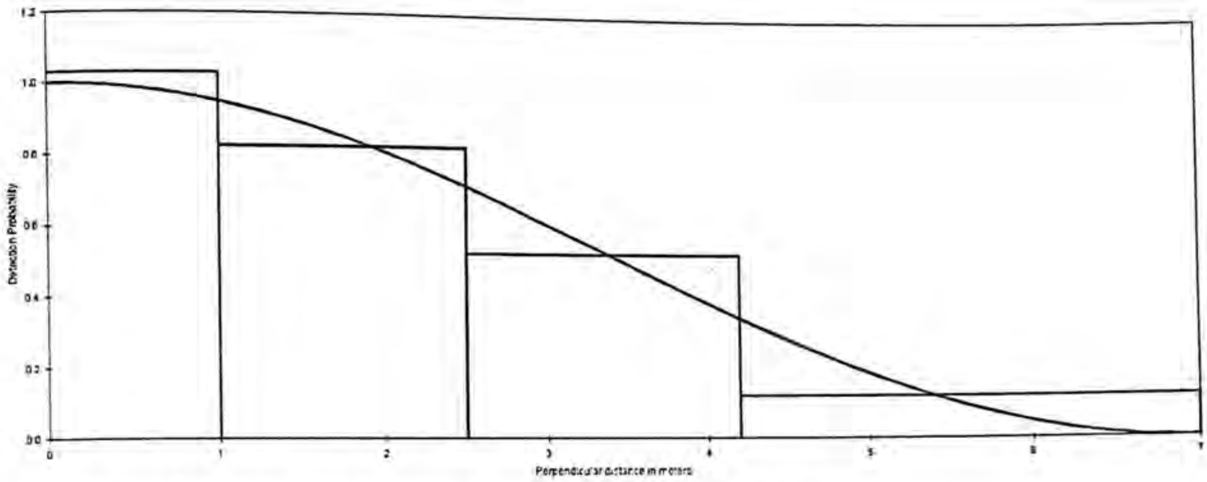

Figure 6.7. Detection probability curves for overall ophidian prey sightings

The Encounter Rate calculated from Distance 6.0 is 1.24 animals/km. The prey density walks were carried out in all classified habitat types (AR_PL= Acacia Plantation; AC_PL= Acacia Plantation; DE_FRST= Dense Forest; MO_FRST= Moderate Forest; PADDY= Paddy field; STRMBD= Stream Bed) for estimating detection probabilities of ophidian species of that area. The Encounter Rate was calculated by the total number of transects walked in each habitat type divided by the total number of sightings of snakes during the walks. From the figure Paddy field shows the highest encounter rate (1.08 animals/km) and this can be attributed to the fact that animals could be easily detected in search paths in these areas due to very less cover followed by Acacia Plantation (0.7 animals/km).

The estimated strip width (ESW) has been calculated to be 3.5 m.

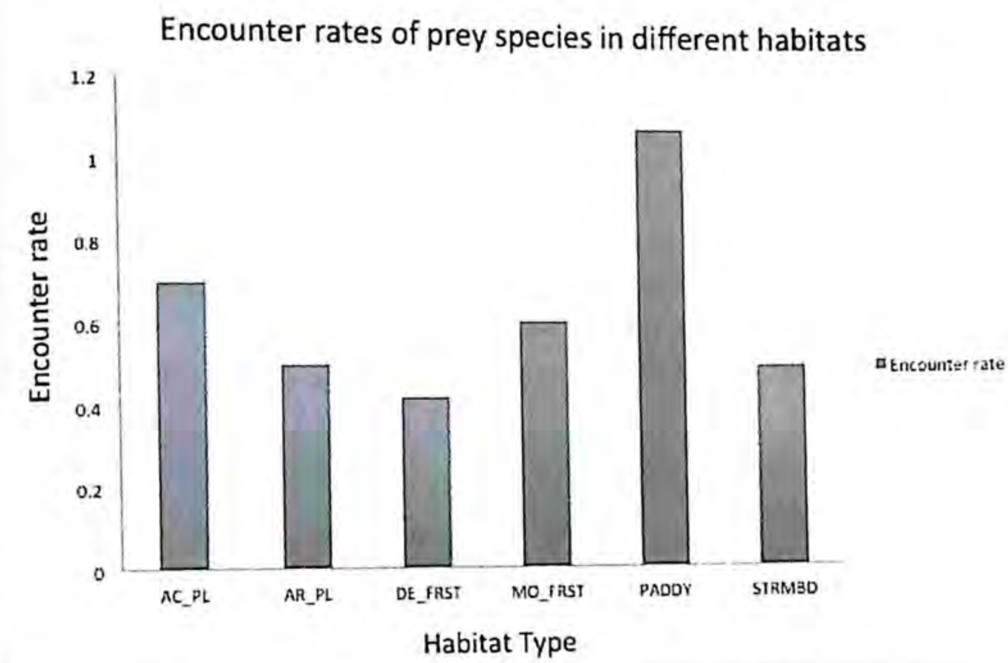

Figure 6.8. Encounter rates of different ophidian prey species per habitat type during the prey density walks

6.3. Results of the third objective: factors influencing distribution

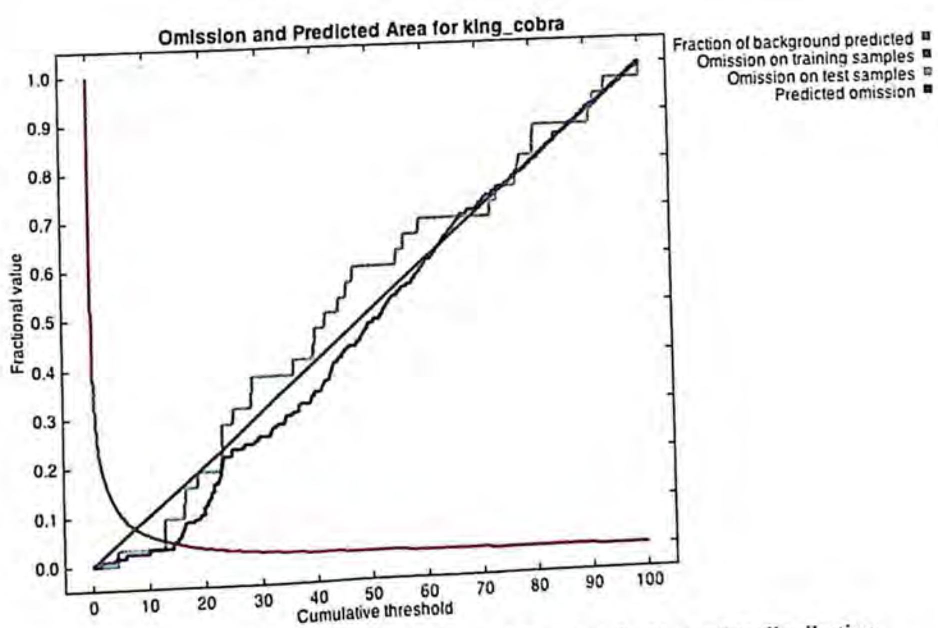

Figure 6.9. MaxEnt predictions of test, training data points for king cobra distribution

Bioclimatic variables 1 (mean annual temperature), 11 (Mean temperature of coldest quarter), 13 (Precipitation of wettest month) and 14 (Precipitation of driest month) were used based on ecological significance and after running a correlation test amongst variables. Note that the response curve of influence of each variable to king presence can be debated if higher correlation exists amongst the explanatory variables. From the graph, we can interpret that the test samples lie on the predicted sample, which explains a better fit to the model. These variables were run on the king cobra presence points (n= 130 presence records used for training, 32 for testing).

Table 6.10. Contribution of bioclimatic variables to the species distribution model

Variable	**Percent Contribution**
Bio13_lcc_img	72.5
Bio1_lcc_img	11
Bio14_lcc_img	9.1
Bio11_lcc_img	7
Extract_wg_img	0.4

The following graphs show the results of the Jackknife test of variable importance, which basically explains the information explained by each variable on the response variable. i.e. presence. The environmental variable with highest gain when used in isolation is bio13_lcc_img, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is bio13_lcc_img, which therefore appears to have the most information that is not present in the other variables. Note that the following distribution is only a pattern based on the data points used while constructing the model.

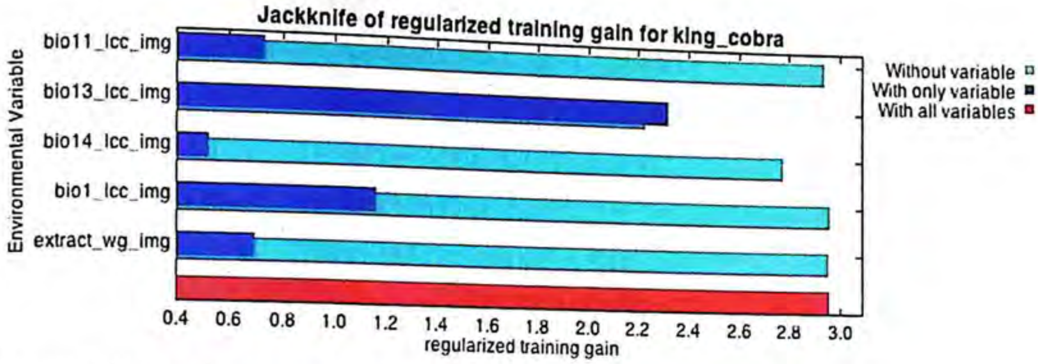

Figure 6.10.1. Jackknife estimates for regularized training gain

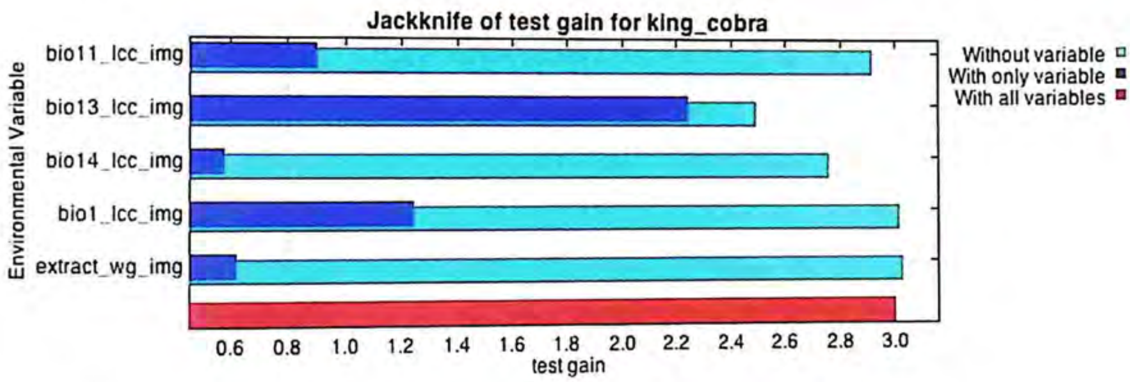

Figure 6.10.2. Jackknife estimates of test gain

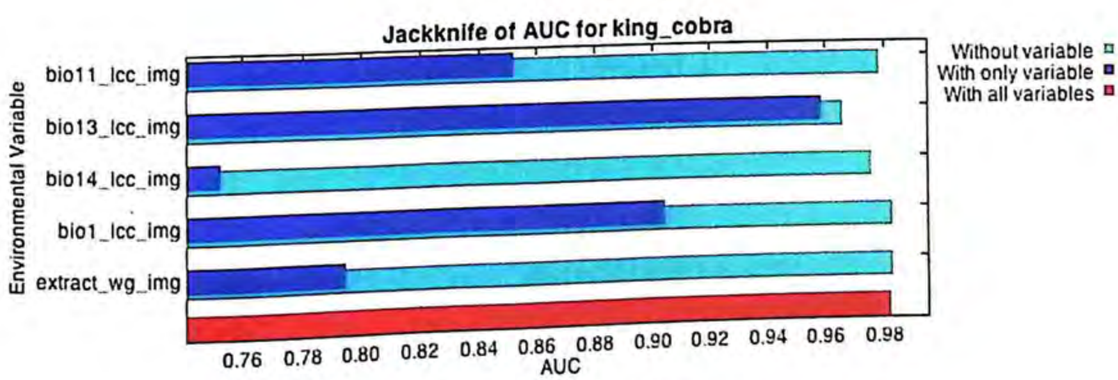

Figure 6.10.3. Jackknife estimates for Area under curve (AUC)

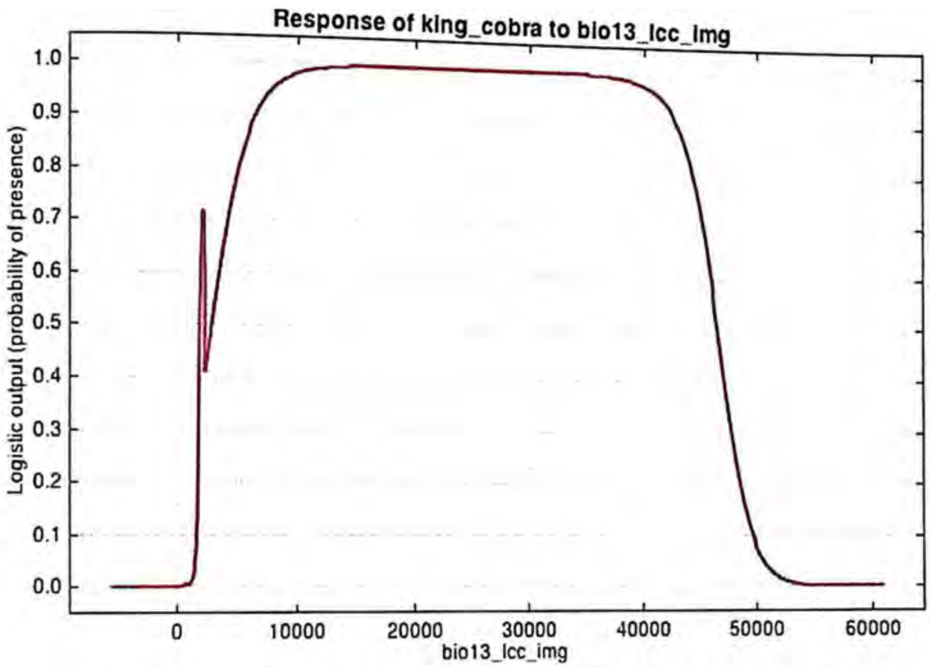

Figure 6.11.1. Response of king cobra presence to precipitation of the wettest month

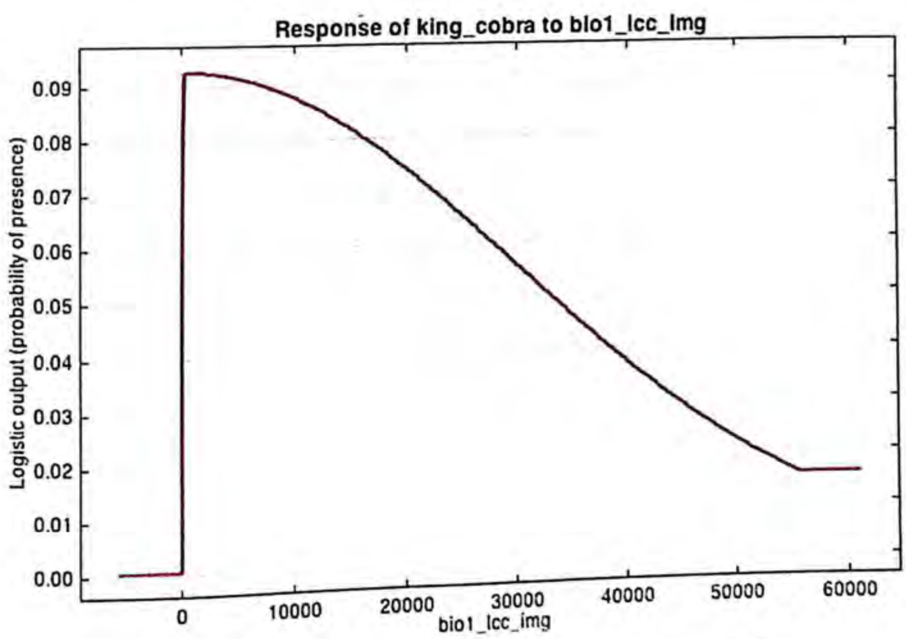

Figure 6.11.2. Response of king cobra presence to mean annual temperature

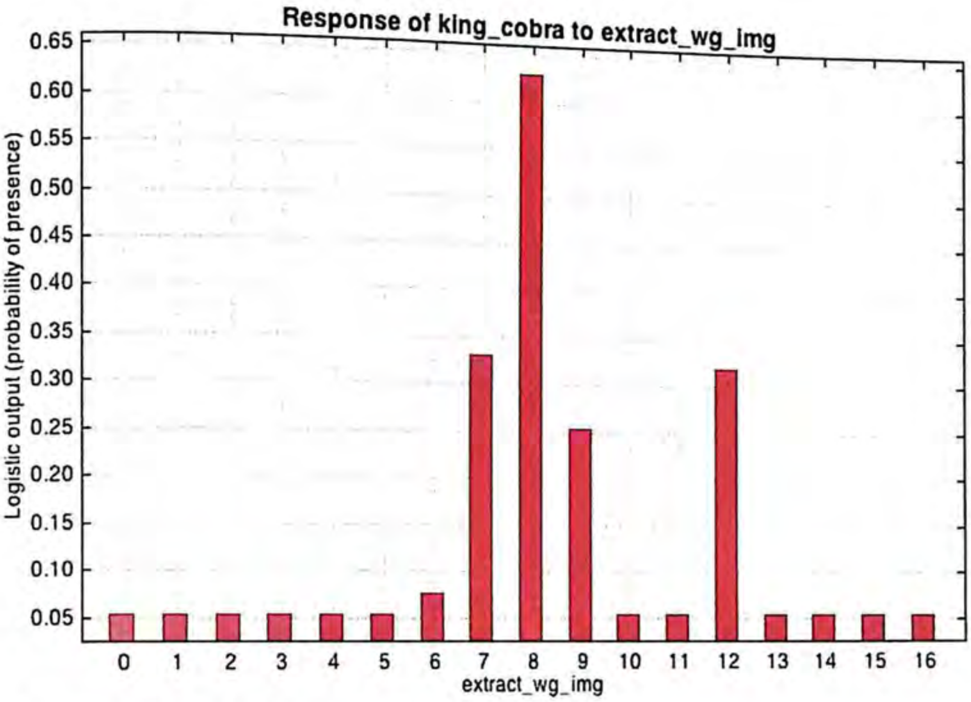

Figure 6.11.3. Response of king cobra to habitat types

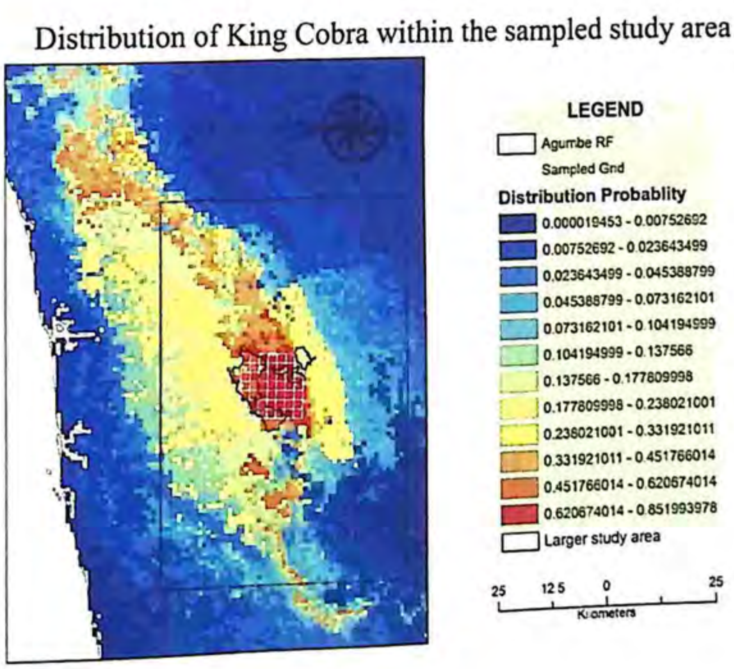

Figure 6.12. Distribution of king cobra in the sampled study area

7. Conclusions and Discussion

Movement pattern

Ophiophagus hannah, like all ophidians, are influenced by a set of environmental and habitat variables which define their habitat use and influence their presence in a particular place. The initial hypothesis was that whether any particular environmental variable influences movement pattern of *Ophiophagus hannah.*

Effect of Ambient temperature (TA), relative humidity (RH) and Wind:

Ambient temperature between 20-35°C and relative humidity between 70-90% and wind direction (W-E) (see Tables 6.2.1-6.2.5) have been found to influence the movement pattern of *O. hannah*. This matches with most reptilian studies as reptiles have very strong correlations with temperature (Huey 1982). This dependence likely affects the fitness of an animal and thus is a very important criterion to test to investigate habitat animal relationships. *Ophiophagus hannah* has a wide distribution and is a habitat generalist in terms of distribution, occurring in a wide variety of biogeographic zones. These facts ascertain the nature of this snake's existence in terms of finer scales that can act on the occurrence and movement pattern of these snakes. These contributing factors (ambient temperature and relative humidity) may also play a limiting role in distribution of king cobra in the area, as they avoid arid, semi arid and desert regions, where ambient temperatures are too high and humidity is very low, where the possibilities of desiccation are higher.

The body temperatures graphs show *O. hannah* maintain a particular temperature for both diurnally and seasonally. This is true for cases of many tropical ophidians where temperature does not vary tremendously and follows a uniform pattern. *O. hannah* body temperatures were constant at 33-34^{0} C for all the radio tagged individuals (Figures 6.1-6.5) while ambient temperature varied from 25-30^{0} C during the study area duration between December 2010- April 2011.

Heatwole (1976) stated that temperature is "almost certainly the most important single physical factor in the ecology of reptiles and a great portion of the daily activity of many species is devoted to responding to the thermal environment". Indeed, numerous studies of habitat use or activity patterns of these ectothermic animals have highlighted the importance of behavioral thermoregulation. The biology of snakes in thermally more stable environments, such as warm water bodies or the humid tropics, has rarely been investigated. Studies show that body temperatures Tb show distinct variation in summer and winter seasons (Schwaner 1989). This distinction could not be seen in the current study as king cobras maintain their Tb between 30-34°C (Figures 6.1-6.5) Also, since ambient temperature variations were not too significant, these Tb is found to be optimal in other ophidian studies as well (Shine and Madsen 1996, Schwaner 1989, Lilywhite 1987, Shine 1987).

Apart from ambient temperature, in the case of tropical ophidians, humidity was an influencing factor for the movement of king cobras. The study area lies in a tropical moist evergreen forest ecosystem where relative humidity conditions remained stable and during monsoon reach very high levels to almost 98%. A direct influence of humidity on these snakes may be answered by the geography of the region. Since water resources are perennial for most of the season in may areas of the Western Ghats, closeness to water may not be significant as desiccation can be avoided by moist conditions. This was also observed in Malayan Pit vipers (Daltry et al 1998) wherein these crotalines showed no thermoregulatory trait of basking and conduction. An alternative explanation for the observed correlation between snake activity and humidity is that the snakes are susceptible to desiccation at low relative humidity, when the evaporative power of the air is heightened as reptiles can lose substantial amount of water through their skin especially taxa from the humid tropics (Heatwole 1976). Other activities such as ecdysis also result in suitable amount of water loss in reptiles (Heatwole 1976; Shankar and Whitaker 2009).

a) Home Range

Males (n=3) show larger home range sizes (mean average 5.5 sq.km for resident males; 54 sq.km for translocated male M1) as compared to females (1.8 sq.km (n=1)). This can be attributed to movement in larger areas in search of mates (Brito 2003, Waldron et al 2006) or in search of prey (Theodoratus 2000). However one individual M1 shows an exceptionally large home range probably because it was a translocated animal and this could be a homing behavior of the animal.

b) Habitat use

Habitat use in snakes is primarily a function of various ecographical factors operating at a microscale (Weatherhead and Prior 1992; Durner and Gates 1993). These factors influence mostly in ophidians at population levels (Reinert 1987). This was hypothesized with relation to a large bodied ophidian species like the king cobra and the influence of climatic variables on its habitat use.

Since the landscape where the study was conducted was a mosaic of habitat types, king cobras moving at random can also be a response to a diversity of prey species occurring in this mosaic landscape, because of heterogeneity in habitat types often leads to increase in diversity of ophidian species (Shine and Fitzgerald 1996, Demers and Weatherhead 2001). The habitat types however, seem to not show any significant influence on movement patterns of king cobras (see Table 6.5). While water bodies, grasslands and agricultural fields are clearly avoided, king cobras tend to prefer evergreen forests. This may be due to the fact a large bodied snake like the king cobra might get too conspicuous in open areas without sufficient cover, camouflage value and availability of retreat sites.

Site selection:

a) Retreat site selection

Ophiophagus hannah mostly selected retreat sites for basking. The amount of sunlight varied significantly during the time of the day. However, these snakes only came out during certain times of the day (forenoon and late afternoons) probably avoiding midday and early afternoon basking, showing a bimodal mode of thermoregulation. This may be attributed to the fact that the predominantly black body color absorbs higher rate of heat than required. Also, these snakes are very alert during most of the times when they were observed, prefer cover and will immediately retreat to hide beneath a fallen log or into dead vegetation at the slightest hint of disturbance.

Thus king cobra presences did show a direct influence of certain microsites with fallen logs and dead vegetation at a macro scale (see Table 6.6). This is an attribute of only adult size class individuals. Juvenile king cobras might use habitats differently more for prey and for cover as they face a higher risk of mortality due to predation. Since the external ambient temperature remains more or less constant, fallen logs may provide excellent cover and basking sites as the animals may be receiving the appropriate thermal quality they need which may be a contributing factor to a site selection (Row and Demers 2006). Preference to fallen logs provide a linear hiding place and these snakes need to bask with their body sprawled rather than coiled. This can be a logical explanation for this kind of preference. Fallen logs also provide good sites for camouflage.

The avoidance of burrows and preference to fallen logs (Table 6.6) may be due to the fact that burrows may be too small for a large bodied snake like *O. hannah*. The hard lateritic terrain might make burrow an inappropriate site along with the fact that that thermal gradient in the study area is not too significant.

b) Nest site selection

Many species of snakes lay their eggs either in burrows, leaf litters, under tiles or fallen logs (Burger and Zappalorti 1991). However, king cobras have been observed to use areas (n=13) with higher levels of dead vegetation and leaf litter depth higher from 4-7 inches (see Table 6.9) as they can be directly linked to suitable sites preferred by females for nest building. It was also observed that leaf litter and other dead vegetation formed the substrata for the nest chamber (Dattatri 1987). King cobra females start building a nest at the end of April and may go on till the first week of May in the study site. Since these areas receive very high rainfall, it is an important priority for the females to select sites with enough substrata to keep the nest chamber dry in the study site. However, disturbance factors (Kannan 1993) could not be accounted as some sites (n=4) were close to human habitation.

Prey Density

King cobras have been observed to feed on rat snakes (*Ptyas mucosa*), common cobra (*Naja naja*), Malabar pit viper (*Trimeresurus malabaricus*) and Hump nosed pit viper (*Hynale hypnale*) (Bhaisare et al 2010). These prey species were scattered in a wide variety of habitats with cobras and rat snakes occupying paddy fields, plantations and forested areas due to availability of rodents while pit vipers are mostly restricted to forested areas. The association of king cobras to smaller drainages (see Table 6.6) is supported of the fact that a large number of ophidian prey species occurred close to such areas. These ophidians depend on hygrophilic prey like frogs and toads, which occur more in moist areas. These sites thus may provide suitable foraging grounds for king cobras. The influence of wind direction might help in finding prey. Observations made on total hours (n=150) of foraging behavior of king cobras and instances of successful hunts (n=4) showed that king cobras have very good cognitive abilities in finding their prey. However, this needs to be further investigated for better answers.

Species distribution and abundance:

MaxEnt is a model used for distribution of species using presence only records (Elith et al 2011). King cobras occur in a very wide distribution. The demographic factors that explain this distribution would vary significantly as they lay in a various biogeographic zones. I wanted to test environmental explanatory variables predicted king cobra distribution and abundance (high, medium and low) to test whether any particular bioclimatic variable signifies king cobra occurrence in the study area. In other studies, ophidian species do show latitudinal richness of species with respect to environmental gradients (Terribile 2008).

From the results, king cobras are influenced by precipitation and rainfall. It is already observed that king cobras are influenced by temperature and humidity at the micro scale. At a larger scale, these variables do influence species distribution as the response curves show a dip in presence response after plateauing to a certain point. However, altitude can also play a role in distribution of reptiles (Bhupathy and Chettri 2010) was not considered, as there is not much significant variation in elevation in the study area. From the maps (Fig) it may be inferred that Agumbe has higher relative abundance than the adjoining areas.

The limitation of this model is the low sample size and the narrow distribution of sample points. Note that in this case, only bioclimatic variables, thought to be ecologically significant have been addressed here and many other important factors such as hydrology, disturbance, roads etc. have not been addressed in the model.

Future directions:

The limitations of this study were a) short time duration b) low sample size and c) cryptic nature of the study animal. Thus to come up with definitive answers in such a scenario would be difficult. However, the present study covers at least two out of the three defined seasons in a study area with a heterogeneous complex of habitat types, including mostly human dominated landscapes. A comparative study in the undisturbed areas will be an efficient way to understand the ecology of this species and thus we will be able to know how human induced changes are affecting the ecology of king cobras. Since the Western Ghats is a unique landscape, it would also be interesting to know how king cobras occur in other areas of their distribution and how their ecology varies geographically. Local adaptations with respect to thermoregulation may also influence king cobra occurrence, it would be interesting to study how these thermoregulatory adaptations, use of hibernaculas, act on populations occurring in other areas from sea level in littoral forests to broad leaf forests (1800 meters). This would enable to answer questions regarding adaptability of the species in the wake of gradual events such as climate change and whether it affects their survival.

Though the study period was short, it has raised more definitive questions rather than definitive answers.

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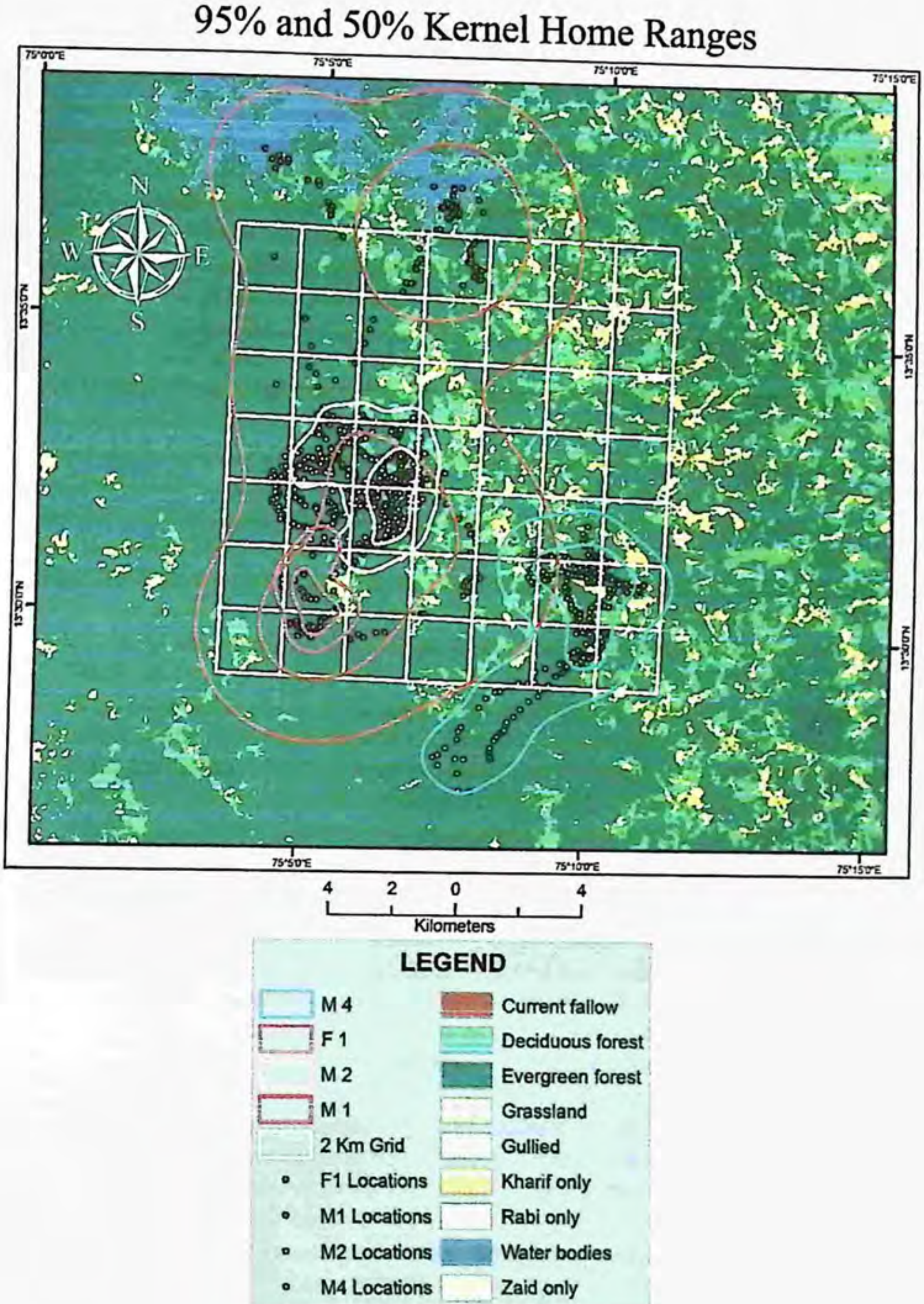
Appendix 1. Kernel home range estimates for the four radio tagged snakes



Appendix 2. Minimum Convex Polygon home estimates for the four radio tagged snakes