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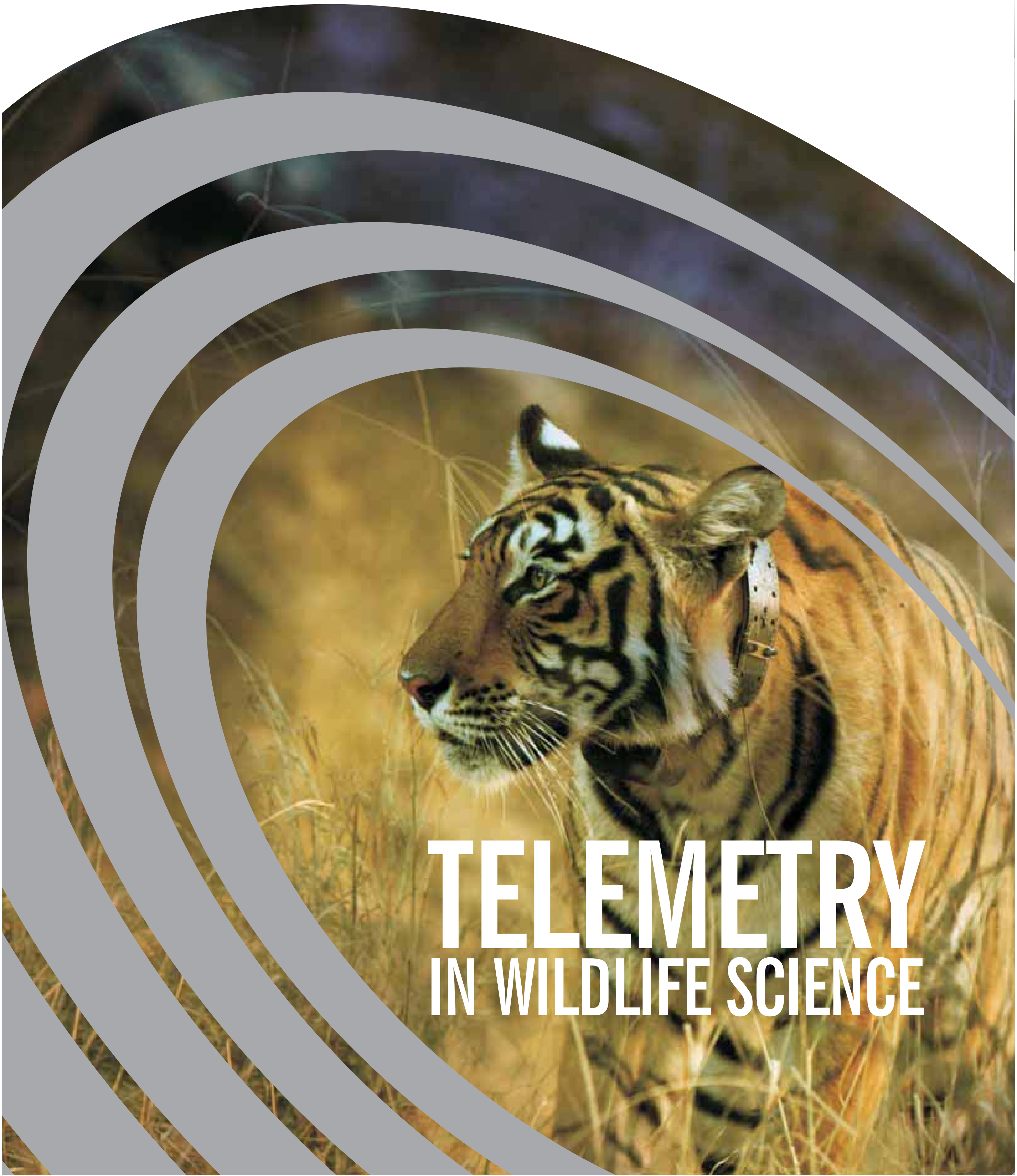

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Envis Bulletin

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TELEMETRY
IN WILDLIFE SCIENCE

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APPLICATION OF RADIOTELEMETRY TECHNIQUES IN SNAKE RESEARCH: KING COBRA (*Ophiophagus hannah,* Cantor, 1836) IN AGUMBE, KARNATAKA, INDIA

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Abstract

Over the past five decades, radiotelemetry has become an increasingly important tool in wildlife field research, providing researchers with the ability to follow individual animals as they live out their often secretive lives. Radiotelemetry studies of snakes have enabled researchers to determine an impressive array of important ecological parameters, including home range characteristics, the fate of translocated animals, and locations of den sites, and documentation of behaviours in the field that would otherwise be extremely difficult to observe. Here, we present data from the first-ever field study of King Cobras (*Ophiophagus hannah* Cantor, 1836) in their natural habitat in the rainforests of Agumbe in Karnataka, south India. Although we have obtained critical data on King Cobra spatial ecology that will ultimately lead to recommendations on how to better conserve these charismatic serpents, of equal or greater interest is documentation of King Cobra behaviours that have never been observed in the wild. We discuss radiotelemetry and summarize yet-to-be published results of this pioneering study of the world's largest venomous snake. We also discuss our efforts to use our data to develop educational programmes aimed at local communities and our ultimate goal of establishing the first-ever sanctuary with a snake as the flagship species.

Keywords

Radiotelemetry, snakes, King Cobra, *Ophiophagus hannah*, rainforest, Agumbe, Western Ghats, India

Introduction

Brief history of snake radiotelemetry

Radiotelemetry has been used in wildlife research since the late 1950s. Early applications of radiotelemetry were primarily for monitoring physiological parameters, such as temperature and respiration (LeMunyan 1959, reviewed in Adams 1965). The use of radiotelemetry to track the movements of animals became popular in the early 1960s, especially in studies of mammal (reviewed in Sanderson 1965) and bird species large enough to carry collars or harnesses containing relatively massive transmitters (Adams 1965). The first use of radiotelemetry in studies of reptiles involved monitoring of both environmental and internal body temperatures in tortoises and iguanas (Mackay 1964). Several years later, researchers began using radiotelemetry to study thermoregulation in snakes, including pioneering work on boas (McGinnis and Moore 1969) and watersnakes (Osgood 1970). The radiotransmitters used in these early studies were only capable of transmitting a signal up to a few metres, requiring that research subjects be maintained in enclosures. In addition, transmitters were force fed, often causing snakes to regurgitate or exhibit post-ingestion behaviour, which further limited the usefulness of radiotelemetry (Kenward 1987).

In the early 1970s, researchers began using radiotelemetry to track the movements of snakes in their natural habitat (Fitch and Shirer 1971, Landreth 1972). Although researchers continued to force feed transmitters, Fitch and Shirer (1971) were the first to implant a transmitter into the body cavity of a snake. Surgical implantation was deemed less useful because the transmitter battery life was only one month, and so by the time the snake recovered from the procedure it was already time to remove the transmitter.

It wasn't until the early 1980s, with the advent of safe and reliable anaesthesia and implantation techniques (Reinert and Cundall 1982), combined with the development of miniaturized transmitters with relatively long-lasting batteries that were specifically designed for internal attachment (i.e., long, cylindrical, and hermetically sealed), that radiotelemetry became a method that was widely used for studying snake ecology (reviewed in Reinert 1992). Now, 30 years later, there is little doubt that radiotelemetry has revolutionized the study of snakes, giving researchers a glimpse into the secretive lives of snakes that would otherwise be difficult, if not impossible, using more traditional demographic techniques. To date, dozens of snake species have been studied worldwide using radiotelemetry, providing information on a wide array of ecological parameters (reviewed in Samuel and Fuller 1996), including movements (*e.g.*, distance and duration, home range), ethology (*e.g.*, diet, predation), demography (*e.g.*, abundance, age, mortality), life history (*e.g.*, growth, fecundity), habitat (*e.g.*, use and preference at varying scales), reproduction (*e.g.*, courtship, combat, mating), and conservation (*e.g.*, effects of translocation, response to anthropogenic disturbance).

Although radiotelemetry has undoubtedly led to fundamental changes in our understanding of snake ecology, it is important to emphasize that it is not a panacea for snake research. Radiotelemetry has a number of limitations that demand closer scrutiny but are often overlooked by researchers. For example, snakes implanted with transmitters are known to grow less compared with snakes without transmitters (Weatherhead and Blouin-Demers 2004, M. Goode, unpublished data).

Radiotransmitters commonly fail prematurely, making it difficult to obtain large sample sizes of individuals that have been continuously tracked (Goode *et al.,* 2008). Furthermore, frequent tracking of radiotelemetered individuals may lead to aberrant behaviour patterns, such as higher movement frequencies (Reinert 1992). Our understanding of snake ecology is clearly biased towards adult snakes and larger species because convention dictates that the transmitter's mass should not exceed 5% of the snake's mass. Advances in technology have led to increasing miniaturization of transmitters, but battery life still limits the usefulness of radiotelemtery for the study of neonate and juvenile snakes and small species. In spite of the many shortcomings of radiotelemetry, it has become the primary means of studying snakes in the wild.

Objectives of the current study

Our primary goal is to obtain in-depth knowledge of King Cobra natural history and ecology through comprehensive field research and to combine this knowledge with educational efforts to develop and implement a conservation plan to protect King Cobras and the habitat on which they depend. We will achieve this goal through the following specific objectives:

- Use radiotelemetry to quantify seasonal movement patterns, home range characteristics, and habitat use of free-ranging King Cobras. Obtain data on body size, reproduction, diet and growth of King Cobras that are "rescued" from the homes of local inhabitants.
- Compare the spatial ecology of rescued snakes that have been translocated with resident snakes that have not been relocated to assess the effects of relocation and to determine its value as a potential conservation tool.
- Describe the thermal ecology of King Cobras, especially females attending nests, using surgically implanted miniature temperature dataloggers.
- Augment radiotelemetry data by remotely determining daily and seasonal activity patterns of King Cobras through examination of temperature data from dataloggers.
- Develop and educational programme targeting local schools and communities in an effort to interest and involve them in conservation of King Cobras and the rainforest environment they share.
- Train Indian college students and local guides to conduct field research using radiotelemetry and other state-of-the-art technologies and methods.
- Use GIS to examine movements of King Cobras in the context of habitat fragmentation, and to use this information to guide future conservation efforts and to predict potential effects of future changes to the environment.
- Provide management recommendations, specifically with regard to the use of translocation as a conservation strategy and based on the habitat requirements of the King Cobra.
- Meet with local forestry officials and other key stakeholders to develop and implement a long-range conservation plan that includes establishment of an officially designated preserve for King Cobras.

Study site and species

The Agumbe rainforest (13° 50' 87.2'' N 75° 09' 59.2'' E) and surrounding farms and plantations were chosen as our study site because we have spent long hours in the field over three decades gaining a better understanding of the high relative abundance of King Cobras in the area (Whitaker, 1980). King Cobras are spectacular animals, growing to over 5 m in total length, which makes them the largest venomous snake in the world (Whitaker and Captain 2007). Surprisingly, very little other than anecdotal information is known about these charismatic serpents in the wild. While they are revered in some parts of India, King Cobras have nonetheless been extirpated from much of their former range, with healthy populations remaining only in a few places (*e.g.*, Agumbe) on the subcontinent. King Cobras in southern India are patchily distributed along the length of the drastically fragmented Western Ghats, from the southernmost tip, Kanyakumari (Black Rock Estate), north to Goa (Bondla Wildlife Sanctuary). The range of King Cobras in this part of India coincides with areas of extremely high rainfall and the corresponding wet deciduous, riparian, and evergreen rainforest (Smith 1943; Fig. 1). Since 2005 we have rescued 110 mainly adult, King Cobras from human dwellings, gardens, wells, and cowsheds in the Agumbe area (G. Shankar, R. Whitaker, unpublished data).

Methods

In collaboration with and permitted by the Karnataka Forest Department, we "rescued" five adult King Cobras that strayed into human dwellings and brought them to the Agumbe Rainforest Research Station (ARRS). We implanted A 25-g temperature-sensing radiotransmitter (Model AI-2T, Holohil Ltd., Ontario, Canada) with a three-year battery life into the coelomic cavities of one female and four male King Cobras. We released the snakes 24 hours after surgery; we released three snakes at their exact points of capture, and we released two snakes >20 km from where they were captured in order to evaluate the effects of translocation as a potential conservation tool.

We radiotracked snakes every day from early morning until nightfall. Depending on the weather conditions, such as rainfall, ambient temperature, and availability of sunlight, these diurnal snakes typically emerged from resting places around 0900 h (range = 0830–1200 h). Trackers always stayed within approximately 400 m of the radiotransmitter signal because even short, undetected movements by the snake could result in losing the signal in the hilly and dense rainforest environment. On days when a snake did not move (i.e., approximately 20 consecutive days during ecdysis), we obtained a radio fix every hour. At each radio fix, we recorded a suite of environmental parameters, including ambient and ground temperatures, relative humidity, and cloud cover. We also obtained data on body temperature based on the pulse rate of temperature-sensing transmitters. We also recorded GPS coordinates and habitat variables, including canopy cover at varying heights, dominant plant species, and shelter type.

If a snake was moving or visible when located, we made every effort to observe its behaviour. Although the initial protocol was to remain out of sight of the snake to avoid influencing its natural behaviour or causing it to move or hide, within a few weeks, we determined that the snakes did not seem to be disturbed when we approached to within approximately 10 m, as long as we remained as still as possible and moved slowly when necessary. The necessity of staying close to the snakes so as not to lose them, coupled with the seemingly relaxed reaction of the snakes to our presence and their large size making them easily visible, has enabled us to make the detailed behavioural observations reported here. When feasible, we kept snakes under sporadic, line-of-sight observation using binoculars. We took detailed notes describing all the movement and behaviours observed. Our efforts to remain with each snake throughout the entire course of its diurnal activity period is unique in radiotelemetry studies. However, we have been rewarded with unprecedented observations of behaviours rarely documented in wild animals, let alone relatively secretive snakes.

Results

Effects of translocation

Radiotelemetry studies on a diverse array of taxa have clearly demonstrated that snakes maintain well-defined home ranges, which are likely mediated through a variety of sensory modalities, including chemoreception, celestial cues, and landmark navigation (*e.g.*, Gregory *et al.,* 1987, Duvall *et al.,* 1990, Reinert 1992, Goode *et al.,* 2009). The ability of snakes to home back has been recognized for decades (Stickel and Cope 1947), and studies of snakes as diverse as tiny worm snakes (Barbour *et al.,* 1969) and sea snakes (Shetty and Shine 2002) have demonstrated that snakes are clearly able to repeatedly return to locations within their home ranges. Removing ("rescuing") snakes from human habitations has become increasingly common, especially as humans have encroached on wild lands. Translocating rescued snakes has become the welcome alternative to killing them on sight; however the fate of the snake, "set free in the forest", is rarely considered. Limited research on translocated snakes indicates that aberrant movement patterns (Dodd and Siegel 1991), and even death, may occur in up to 50% of individuals (Reinert and Rupert 1999) as they frantically try to home back to familiar surroundings. Although we presently do not have a large enough sample size to say for sure whether or not relocation affects the survival or reproductive success of King Cobras, a comparison of two males, which we have tracked for longest periods of time, is both dramatic and indicative.

M1 – Translocated snake

We implanted a radiotransmitter into a translocated male King Cobra (ID = M1, mass = ca. 6,000 g, snout-vent length = 266 cm, tail length = 55 cm) in March 2008 (Figs 1, 2). We tracked the snake for 298 days, during which time it moved a total linear distance of 76.6 km based on GPS coordinates. Because we tracked the snake as it moved between locations, we were able to reasonably estimate the total distance moved to be 91.2 km. We obtained estimates of the actual distance moved by comparing the distance between successive locations with locations taken every 200 m, which yielded a correction factor of 1.2 km. Therefore, the total linear distance of M1 of 76.6 km multiplied by the correction factor of 1.2 km equals 91.2 km, the total distance moved. Because snakes move in three dimensions, computing uphill and downhill movements would result in an even larger correction factor, which we plan to refine as additional data become available. The "home range" of the snake (likely not the actual home range because the snake was translocated), as computed using the minimum convex polygon method, which simply draws a straight line between the outermost locations, was 124 km^2.

We rescued M1 from a house > 40 km from Agumbe and released him ca. 2 km from ARRS at Agumbe. During the entire time we tracked M1, he exhibited straight-line, rapid, strong movements, never returning to a fixed activity centre. M1 travelled 6.1 km in a

Figure 1

Close up of insertion of radio transmitter in M1

Figure 2

M1 after implanting transmitter, prior to release

single day, which is possibly a world record for the distance moved in a single day by any snake species. The rapid and incessant fixed-angle movements, zigzagging across a huge area, suggest that M1 was disoriented and unable to home back to familiar territory (Figs. 3, 4). These seemingly aberrant movements are precisely what would be predicted for a translocated snake based on other studies (Plummer and Mills 2000, Nowak *et al.,* 2002, Butler et al, 2005); we predict that a larger sample size of translocated and non-translocated snakes will likely provide further support for these preliminary conclusions. The conservation implications of our extensive observation of the movements of the first-ever translocated snake in India are obvious. With so many thousands of snakes being "rescued" and relocated to potentially unsuitable habitats all over the country, it seems likely that mortality in translocated snakes may be high.

M2 – Non-translocated snake

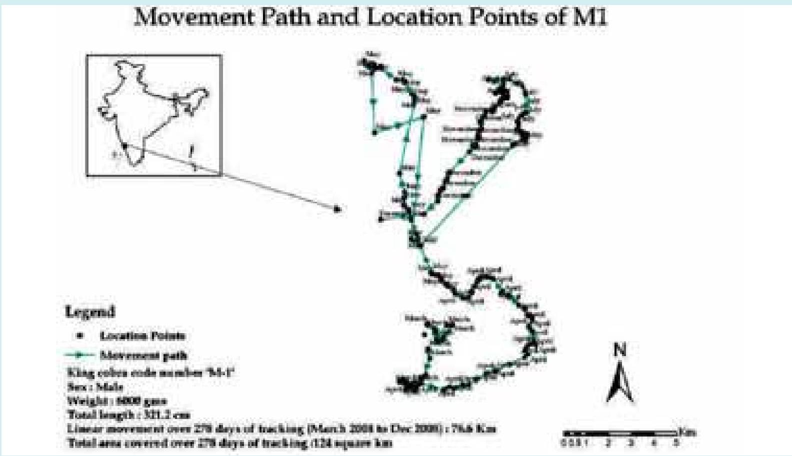
We implanted the non-translocated male (ID = M2, mass = 4,900 g, snout-vent length = 263 cm, tail length = 59 cm) in March 2009. We tracked the snake for 326 days, during which time it moved 58.6 km actual distance, compared with 92.1 km for M1, the translocated snake.

M2 was rescued and released at his original point of capture ca. 2 km from ARRS. Over the next two days, the snake moved 2.3 km, climbing down the steep Agumbe escarpment, where the signal was lost. We found the signal, 6 km away from where we lost it, ten weeks later, on 7 June 2009 after incredible perseverance by the tracking team. During the 326 days we tracked M2 (we are currently still tracking the snake), he has utilized a definite centre of activity, revisiting exactly the same shelters and foraging sites multiple times. Remarkably, M2 and another male snake, M4, have both returned multiple times to the same termite mounds, where they evidently prefer to shed their skins during the roughly 20-day ecdysis cycle. M2's movements have covered a

Figure 3

Daily Generated Google map of total movement of M1 over 278 days of tracking

Figure 4



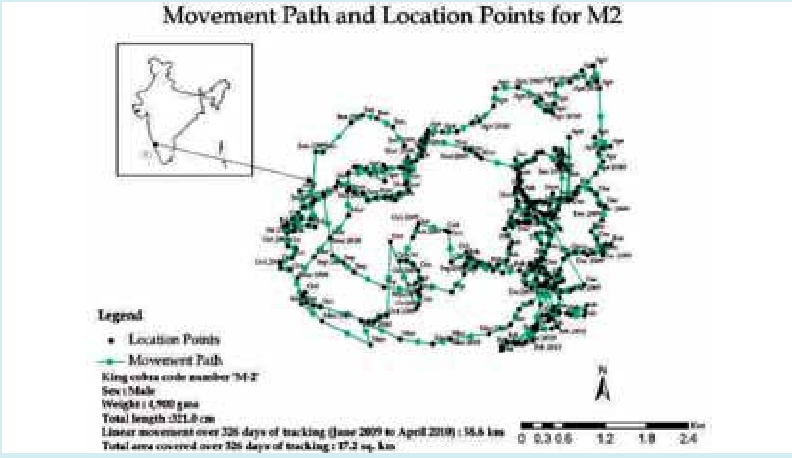
Movement and location points of M1 based on Google map

conspicuously circular area encompassing ca. 18 km^2 (and to which we are tentatively referring as his "home range")(see Figure 3), about one-seventh the area covered by M1. We infer from these data that M2 is familiar with the area he has been using, and preliminary data indicate that he uses different habitats because of seasonal prey preferences (see *Diet*). It seems likely that male King Cobras follow female scent trails during the breeding season, meaning that they may be establishing transient or temporary territories in addition to the normal home range, where they even defend access to females via male-male combat (Shankar *et al.,* in review). Chippaux (2002) proposes that territory size (we prefer to call them home ranges due to the social functions of territories that are not known to occur in snakes) in snakes should be proportionate to body size and energy requirements. In most snake species studied to date, male home ranges are on average three times greater than female home ranges, and searching for mates increases their contact, and therefore potential conflict, with humans. Chippaux provides examples of "territory" size in several smaller snake taxa (*Vipera berus* (European Adder) = 2 ha; *Coluber constrictor* (Black Racer) = 12 ha; Crotalids (rattlesnakes, USA) = 8-28 ha; *Bitis gabonica* (Gaboon Viper) = 0.8-1.6 ha), and they are predictably much smaller than our preliminary estimates for King Cobras.

Diet and predation

Large, active snakes, such as King Cobras, which may weigh up to 10,000 g, presumably require a considerable amount of prey to sustain themselves. In captivity, adult male King Cobras, averaging 350 cm in length and 6,500 g in mass, are known to consume an average of two to three adult rat snakes (*Ptyas mucosa* Fitzinger, 1843) per month. The mean length/weight of a rat snake is 175 cm/1,250 g (R. Whitaker, G. Shankar, unpublished data), which translates into roughly 30,000 g of prey per annum. Indian Rat Snakes and Spectacled Cobras (*Naja naja* Linnaeus, 1758) are both confirmed prey species of King Cobras in our

Figure 5



Movement and location points of M2 based on Google map

study area, and both species are particularly abundant near agriculture and human settlements, likely due to a high density of commensal rats. We suggest that the attraction of snakes that feed on rats associated with human habitations likely accounts for the frequency with which King Cobras need to be rescued. Indeed, preliminary analysis of our radiotracking data reveals that King Cobras spent an average of 22% of their time in landscapes created and/or dominated by humans.

Tracking M2 has led to important and unique insights into seasonal food preferences, which appear to be based on availability. During the height of the monsoon season (June-September) in Agumbe, both Indian Rat Snakes and Spectacled Cobras are less likely to be encountered compared with other times of the year. We naively assumed that M2 would be less active during the monsoon season, especially in Agumbe, where the annual rainfall averages over 7,000 mm, peaking at over 11,000 mm. We also assumed that heavy and persistent rainfall would cause feeding to taper off until the return of warmer, dryer weather. However, we first observed M2 finding, killing, and eating a Malabar Pit Viper (*Trimersurus malabaricus* Jerdon, 1854) on 6 July 2009 at the height of the rainy season (Fig. 6). Over the following 135 days, we observed M2 eating a total of 26 pit vipers, two of which were diminutive Hump-nosed Pit Vipers (*Hypnale hypnale* Merrem, 1820). At an average weight of ca. 50 g, these small "meals" totalled only about 1,300 g, the average weight of a single Indian Rat Snake. It seems unlikely that this seemingly small amount of prey would not comprise an adequate maintenance diet for a large, active snake averaging ca. 5,000 g over an 18-week period (Bhaisare *et al.,* 2010). Given our almost moment-to-moment surveillance of M2, however, we are reasonably confident that our observations of predation comprise the vast majority of prey captured.

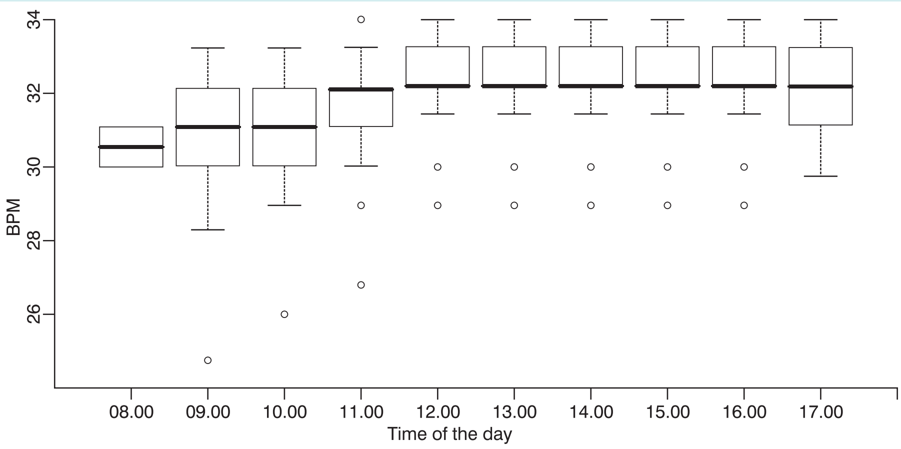
Figure 6

M2 killing a pit viper (Trimeres-urus malabaricus) (note retaliatory bite)

Thermoregulation

We quantified the body temperatures of the radiotelemetered King Cobras every hour during their diurnal active phase (ca. 0800-1730 h). We calculated body temperatures from calibration curves supplied by the manufacturer for each transmitter, correlating pulse rates (beats per minute, BPM) to body temperature. Body temperatures were relatively low when snakes emerged from

Graph 1



Box-plot showing increase in diurnal body temperatures of King Cobra M1.

nocturnal shelters but increased by mid-morning (ca. 1100 h, see Graph 1), when snakes typically basked in direct or dappled sunlight. M1 maintained body temperatures between 28.9 and 34.8°C (x = 32.3°C) throughout all seasons.

Shelter Sites

Both M1 and M2 frequently used termite mounds, tree buttresses, bushes and thick shrubs, fallen logs and canebrakes, burrows, trees, crevices (under rocks), leaf litter, and bamboo thickets as temporary diurnal shelters and nocturnal resting sites. We plan to analyse the time spent in various shelter sites relative to their availability and in the context of thermal selection as we obtain more data on snake activity patterns, including time spent basking, foraging, and resting.

Cannibalism

Cannibalism has been frequently documented in snakes (cf., Mitchell 1986), and we have observed cannibalism in both wild and captive King Cobras on several occasions (also see *Male combat*).

We translocated a female King Cobra (F1) implanted with a radiotransmitter, releasing near Agumbe on 12 March 2008. In two weeks, she covered a distance of ca. 1.5 km and was visited by two non-telemetered male King Cobras on 28 March 2008. On 4 April 2008, we observed F1 capturing, killing, and consuming an Indian Rat Snake.

On 17 April 2008, we lost visual sightings of F1, and her signal appeared to be coming from the direction of a large, non-telemetered male King Cobra that we observed resting in a dense *Pandanus* stand where the female was last sighted. On 18 April 2008, we observed the male King Cobra, which had obviously recently fed, lying in a loose coil, and F1's signal continued to come from the direction of the male snake.

On 27 April 2008, we attempted to obtain a visual sighting of F1. Upon close approach, we found the decomposed body of F1, with the head and neck partially digested. Based on our observations and an earlier, similar observation on a non-telemetered female (see *Male Combat*), we inferred that the non-telemetered male had killed, swallowed, and regurgitated the female.

Male combat

We made opportunistic observations of male-male combat involving non-telemetered male King Cobras in our study area. We observed several instances of male-male combat in 2007 (three times at one location), 2008 (one incident) and 2010 (twice at two locations) (Fig. 7). Although the frequency and duration of combat differed, a female King Cobra was always present, and combat always occurred during the breeding season.

In one case, in 2008, at Chokadabyle (35 km from Agumbe), male combat between the "resident snake" (which had been with a female for several weeks) and an intruder, the snake that "won" the contest approached the female, and after a brief courtship attempt, killed, swallowed, and regurgitated her. Because we were unable to distinguish the male snakes from one another (neither was equipped with a radiotransmitter), we were unsure as to which snake ingested the female. Given the relative frequency with which we have observed cannibalism (i.e., intraspecific predation), it seems likely that it may be a more common phenomenon than previously thought.

Courtship, mate guarding, and mating

During typical courtship in King Cobras, the male approaches the female and flicks his tongue over her body, while occasionally chin rubbing and head butting her (Whitaker, *et al.,* 2005; Shankar, Whitaker and Whitaker, in review). When the female relents, she

Figure 7

Male combat in king cobras invariably occurred in the breeding season and in the presence of a female king cobra

typically spreads her hood horizontally on the ground and usually coils her body. The male then moves over the length of her body with a jerking motion, finally lifting her tail with his tail to access the cloaca. We have observed mating to last from a few minutes to nearly an hour.

We observed mating behavior being displayed by M2 in April 2010, which was the snake's first mating season after being telemetered. On 7 April 2010, we observed a female King Cobra approaching M2, appearing to chase him into a bush. We then observed M2 approaching the female from behind, remaining erect with his hood raised. The female also hooded up, facing away from M2. Soon after, we observed courtship behavior, during which M2 remained in close proximity to the female, constantly flicking his tongue close to and on her body. The female then coiled up and hid her head under her body (submissive behaviour often observed by us) while M2 continued to rapidly flick his tongue, pushing at her coils and simultaneously twisting his tail with hers in an obvious attempt to mate. This behaviour lasted approximately 15 minutes, after which M2 began to move away, only to be followed by the female. They then separated but within an hour were together again and resumed courtship, which lasted roughly 20 minutes. We did not observe the female again after that day.

Ecdysis (skin shedding)

We released M1 on 17 March 2008 and tracked him for about nine months (278 days). We recorded behavioural data every day, which allowed us to accurately ascertain the timing and duration of ecdysis. M1 shed his skin three times over the 9-month period, remaining quiescent for a total of 32 days (7 days from 28 April to 5 May 2008; 10 days from 24 August to 2 September 2008; 15 days from 1 to 15 November 2008.

We released M2 on 28 March 2009. We have tracked the snake for over one year, observing ecdysis on four occasions (21 days from 20 September to 11 October 2009; 20 days from 24 November to 12 December 2009; 26 days from 12 January to 8 February 2010; 20 days from 3 to 23 March 2010.

We were surprised at how often King Cobras shed their skin, considering many snake species, as adults, are known to shed only once or twice per year, depending on their growth rates. We plan to gain a better understanding of shedding duration and frequency as our sample size increases. It is important to understand the factors responsible for ecdysis, given its importance to the life histories of snakes that are forced to remain inactive and vulnerable to predation during the shedding cycle.

Discussion

To date, we have tracked one female and four male King Cobras for varying periods of time. During this time we have observed several never-before-documented behaviours. For example, one translocated male snake moved over 90 km during a 9-month period, possibly a world record for snakes and a strong indication that translocated snakes spend considerable time and energy trying to "home back" to their home range. In the relatively brief time we have been tracking King Cobras, we have also documented a wide array of behaviours, including male-male combat, mate guarding, courtship, mating, predation, and two instances of cannibalism. Perhaps most importantly, we have documented habitat use by King Cobras in the mosaic of reserved forests, revenue forests, plantations, gardens, rice paddies, urban areas and private residences. Ultimately, these data will be used to inform the management of King Cobras, which is becoming increasingly important in the face of the ever-growing human population and associated habitat fragmentation. We hope that our ecological data, combined with our educational efforts, will lead to a greater understanding of the plight of King Cobras and the rainforest habitats on which they, and such a wide array of other species, depend. Most of our findings about the wild behaviour of King Cobras would not have been possible without the technology of radiotelemetry.

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