

**SPATIO-TEMPORAL AND THERMAL ECOLOGY OF INDIAN ROCK
PYTHON (*Python molurus*, Linn. 1758) IN SATHYAMANGALAM AND
MUDUMALAI TIGER RESERVES, TAMIL NADU**

THESIS SUBMITTED TO THE
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For
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DOCTOR OF PHILOSOPHY IN FORESTRY
(WILDLIFE SCIENCE)



By
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DECLARATION

I hereby declare that the thesis entitled “*Spatio-temporal and thermal ecology of Indian rock python (Python molurus, Linn. 1758) in Sathyamangalam and Mudumalai Tiger reserves, Tamil Nadu*” submitted by myself, Mr. Vishnu C.S (Enrolment No. 18PHD512), to Forest Research Institute Deemed to be University, Dehradun for the award of the degree of **Doctor of Philosophy in Forestry (Wildlife Science)** is a record of original research work carried out by me under the supervision of Dr. Ramesh Chinnasamy, Scientist-E and Dr. Gautam Talukdar, Scientist-F, Wildlife Institute of India, Dehradun and has not formed the basis for an award of any other degree or diploma. I also declare that the thesis embodies my own work, observations, and analysis, and in that respect, the investigation appears to advance knowledge in the subject.

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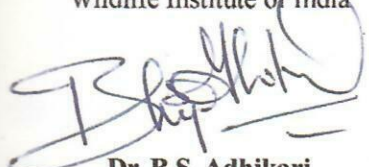
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VISHNU.C. S

The Indian rock python (*Python molurus*) is a Schedule I species in the Indian Wildlife (Protection) Act-1972. It is also listed as appendices I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) since they face immense survival threats due to habitat degradation and poaching. A few studies on this species have been done in the northern part of the country, but no research was available from the southern region of India. The microhabitat preference, home range information, homing behaviour, and thermal requirements of this species are completely lacking. This study aimed to assess those important aspects of this species. Before the major research objectives, I reviewed the snake telemetry papers between 2007 and 2017 and identified the suitable transmitter and anaesthetic for the study. It was found that the VHF AI-2 Hollohill model was the best transmitter for the study due to the animal's body plan, whereas the Isoflurane gaseous anaesthesia can be a suitable anaesthetic agent.

Microhabitat Use

Understanding the microhabitats used by a species is essential for its effective conservation and management. This study objective aimed to quantify the microhabitat use of Indian rock pythons in the Sathyamangalam and Mudumalai Tiger Reserves (STR & MTR), Tamil Nadu. Fourteen pythons were captured through intensive search and opportunistic methods from STR, MTR, and nearby villages and then radio-tracked between 2018 and 2020. The various microhabitats were categorized and quantified based on sightings of the radio-tagged pythons. A total of 401 microhabitat locations were collected and classified into eight categories: burrows, dead fallen trees, dry bushes, green bushes, trees, open areas, rock crevices, and water. The study found a significant association between male and female microhabitat use ($\chi^2 = 29.40$, $v=7$, $p < 0.001$). The number of sightings was converted into proportions, revealing that dry and green bushes were the most preferred

microhabitats for pythons, irrespective of sex. This study provides valuable insights into the microhabitat preferences of Indian rock python in tropical climatic conditions. It can help in the formulation of effective policies and measures to protect this species and its habitat.

Homing Behaviour

Homing is often a critical aspect of an animal's behavioural and spatial ecology. Translocation is considered a wildlife management strategy that could reduce human-wildlife confrontation. Still, this strategy may not be effective if animals attempt to go home to their original capture location. Translocation of animals from sites where possible human-wildlife interaction occurs is a widespread but controversial intervention to resolve conflicts. In India, snakes are often the subject of such translocations, but there is a paucity of information on the behaviour of translocated snakes compared to resident snakes. The Indian rock python is one of the largest carnivores of the Indian subcontinent and is listed as Near Threatened by the IUCN. We radio-tracked the movements of 14 adult Indian pythons for two years (December 2018 to December 2020) in the Moyar River Valley. Eleven of the 14 pythons were translocated 0.2 -55.7 km from their capture locations, while three pythons were not translocated: six were translocated short distances (<5km from capture), two were translocated medium distances (9-11km from capture location), and three were translocated long distances (21 – 55.7km from capture location). The four of the six snakes translocated short distances all returned to within 500m of their original capture locations, and all six returned over 60% of the translocated distance home. Of the two snakes translocated medium distances, both returned to within 1.1km of the capture location (~90% of the distance home). None of the snakes that were translocated long distances successfully returned to their capture locations. Translocated pythons exhibited

greater movement distances than resident snakes within the first two months of release. Based on these results, long-distance translocation may be an effective strategy to minimise human-python conflict, while short or medium-distance translocation is unlikely to be successful. However, more research is needed about the long-term survival of translocated snakes as well as soft-release methodologies that could prevent aberrant movement behaviour directly following release.

Home Range

We hand-captured the 14 Indian rock pythons from villages, agricultural lands, and core forests to examine the home ranges. We later released/translocated them in different kilometre ranges at the Tiger Reserves. From December 2018 to December 2020, we obtained a total of 401 radio-telemetry locations. The average tracking duration was 444 ± 212 days, and 29 ± 16 data points were collected per individual. We quantified home ranges and measured morphometric and ecological factors (sex, body size, and location) associated with intraspecific differences in home range size. We analysed the home ranges of Indian rock pythons using auto-correlated Kernel Density Estimates (AKDE). AKDEs can account for the auto-correlated nature of animal movement data and mitigate against biases stemming from inconsistent tracking time lags. Home range size varied from 1.4 km² to 8.1 km² and averaged 4.2 km². Differences in home range sizes could not be connected to body mass. Initial indications suggest that Indian rock python home ranges are larger than other pythons.

Thermal Ecology

Temperature plays a crucial role in the physiology of snakes. However, only very limited studies on python thermal biology have been carried out in tropical regions. Here we recorded body temperature (BT) changes of the celomic cavity with respect to atmospheric temperature (AT) and relative humidity (RH) of five Indian rock pythons in the field. The

monitoring of the python's thermal ecology lasted throughout 2019 and 2020 and included all seasons i.e., monsoon, post-monsoon and summer. We tagged 13 pythons with iButtons, but we were only able to retrieve data from five individuals. The AT and RH contributed significantly to the maintenance of the pythons' BT. Generally, python BT positively related to the AT and negatively to RH i.e., an increasing AT led to an increasing python BT, while an increasing RH led to a decreasing BT. RH played a crucial role in python body temperature regulation; this could be attributed to the high humidity during the rainfall. Python BT varied inter-seasonally and individually, indicating that python BT varied according to the surrounding AT. However, BT differed between the sexes. Our study provides baseline information for further studies on how environmental factors affect the physiology of large -bodied snakes in tropical climates.

Human-Python Conflicts

From these results and previous studies, we have formulated a few recommendations and suggestions for conservation and reducing the conflict. In the study area, it was found that 21.3% (n = 137) of people reported livestock loss due to pythons. Additionally, the same study revealed that 86.5% of respondents in the study area had strong negative perceptions of snakes. Pythons were one among the most frequently sighted snake species by the respondents, accounting for 17% (n = 179) of the sightings.

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1.1. Reptile fauna

The reptiles are scaled vertebrates diversified and colonised throughout the world except for the extreme poles like Antarctica (Pincheira-Donoso et al. 2013). They are a rich species class that constitutes about 10196 species (Cox et al. 2022). The reptilians include four major subclasses, Anapsida, Diapsida, Synapsida and Parapsida, based on the number and the absence of temporal fenestrae or fossae in the skull. Among the four, two are extant (Anapsida, Diapsida), and two are extinct (Synapsida, Parapsida) subclasses. All the reptiles except chelonians are placed under Diapsida, whereas chelonian, which comprises turtle, tortoise and terrapins, are placed under Anapsids. Reptiles confined under Class Reptilia consist of four major clades: Squamata, Testudines, Crocodylia and Sphenodontia (Norsdorm et al. 2022). Squamata is a clade that includes lizards, snakes and amphisbaenians, which constitute the highest species among the overall clades, making it the most diversified terrestrial vertebrate (Pyron et al. 2013; Da Silva et al. 2018).

Birds evolved from reptiles, and hence, they shared a common ancestor, but reptiles being paraphyletic don't surge to include birds, and thus they are distinctively termed as non-avian reptiles by their habitat functionality and body forms according to their diversity (Pincheira-Donoso et al. 2013; Szabo et al. 2021). Reptiles are often confused with amphibians due to their collective inclusion and understanding in herpetology. The recurrent notion has the mandate to showcase reptiles to be finitely differentiated from amphibians with a known fact of their diverged independence as two separate lineages happened to be dated at least 300 million years (Pough et al. 1998). Reptiles

are very diverse in that they are adapted to inhabit different habitats around the world that envelope temperate, tropics and arid geographical regions (Böhm et al. 2013), but given their poikilothermic nature, they tend to prefer warmer belts the most (Chippaux 1998; Chippaux 2011; Mohapatra et al. 2011). Being poikilothermic and uricotelic, they are better adapted towards the warmer belts and are known to handle various types of thermoregulatory behaviours for their survival. Some types include thigmothermy through basking and burrowing, shivering thermogenesis and kleptothermy (Girons 1980; Brischoux et al. 2009).

The population is, although a measurement that needs a long-term monitoring approach (Tinkle 1979), despite being factual that reptiles are the least understood, there are scientific figures that show a mass decline of more than 55% in the past half a decade (Saha et al. 2018). Anthropogenic threats have alarmed 21 % of global reptilian fauna (more than 1800 species) to pertain extinction risk in the current scenario, which was lacking compared with other taxa (Cox et al. 2022). Reptiles inhabit various habitats and geographic realms, which would need priority to the place and change in strategy for conservation practices (Roll et al. 2017).

1.2 Snakes

Snakes are important taxa under Class Reptilia and Suborder Serpentes, which contributes the high number of species along with lizards under the Squamata clade (Da Silva et al. 2018); most of the extant snakes are placed under Caenophidia, which comprised the largest family Colubridae (Vidal et al. 2007; Uetz et al. 2023). Their distributions extend throughout the world except for Antarctica and other regions like Iceland, New Zealand, Ireland and Greenland, which were unlikely during diversification due to geographic isolation and unsuitable paleoclimate. The origin of

snakes baffled scientists to understand their limbless nature, which would lead towards understanding the evolutionary connection between lizards and snakes. A recent study by Silva et al. (2018) unveiled that the common ancestor of all snakes had a terrestrial form without a fossorial lifestyle. Snakes are known to showcase a great evolutionary transition from being tetrapod. The evolution of body morphology in snakes resulted in a limbless nature in modern snakes (Leal and Cohn 2018). This snake-like form, however, has been evolved multiple times in squamates (Brandley et al. 2008). The limb loss is reasoned with the sonic hedgehog gene, which is completely absent in modern snakes but present in the old-world snakes like Pythons and boas but inactive due to DNA mutations (Kvon et al. 2016; Leal and Cohn 2018). There are 4038 snake species in the world under 7 Superfamilies, 30 families and 45 sub families, excluding the two subfamilies (Ateuchosauridae and Ristellidae), out of these, there are 8 families and 3 subfamilies that don't have ascertained with a superfamily (Uetz et al. 2023).

Serpents are often understood in different perspectives since more than a century. Ophidians have been portrayed as dual symbolism; for example, *nahash* an ancient serpent figure, represents as an evil omen and healing power (Skinner 2000). They have ideally been portrayed as an ecologically important component, and on a religious way forward, snakes have symbolised life, power, fertility and sexuality (Araújo and Ely 1978; Freitas 1999; Marcum 2007). The snakes are studied throughout the world in several major aspects like taxonomy (Deepak et al. 2018; Mallik et al. 2020; Mallik et al. 2021), snake bite (Gutiérrez et al. 2017), venomics (Calvette et al. 2007; Lomonte and Calvette 2017; Slagboom et al. 2022), thermal biology (Seebacher and Franklin 2005; Giacometti et al. 2021; Crowell et al. 2021), evolution (Gibbs et al. 2018; Da Silva et al. 2018), climate change (Lourenço-de-Moraes et al. 2019), invasiveness and

spatial ecology (Piquet et al. 2021; Leatherman 2022; Natusch et al. 2022). A potential implication of science has also produced benefits for human survival, like the role of snake venom in drug discovery (Mohamed Abd El-Aziz et al. 2019).

Venomous snakes kill more than 100,000 people and cause injury to more than 400,000 people in the world per year (Gutiérrez et al. 2017).—India boasts approximately 361 snake species, with 73 of them posing a venomous threat to humans. Among these, 15 stand out as significant contributors to human casualties, with four of these species being particularly widespread and responsible for a considerable number of snakebite incidents in India (Whitaker and Martin 2015; Das and Das 2017; Ramesh and Nehru 2019). At the same time, snake venom has been used to create an important drug for implication in the ecosystem in a bio-controlling aspect. Snakes predate and control rodents, which destroy economic crops. Also, drug discoveries through snake venom help save people from various diseases (Mohamed Abd El-Aziz 2019). The venoms from snakes consist of a combination of biologically active components that play a role not only in envenomation pathophysiology but also in the development of new drugs to treat various diseases (Vyas et al. 2013). In Ayurveda, cobra venom was historically employed to alleviate joint pain, inflammation, and arthritis (Gomes 2010). Furthermore, cobra venoms have been utilised for centuries in Chinese medicine to address opium addiction, and in India, they were combined with opium for pain relief. Additionally, other bodily fluids from snakes, such as blood and bile duct secretions, have found extensive use in traditional Chinese medicine (Koh et al. 2006).

1.3 Pythons

The pythons are large, constricting, non-venomous and compact snake species which compose the old-world ophidian lineage (Henderson and Powell 2007; Reynolds et al. 2014; Zaher and Smith 2020; Uetz et al. 2023). They are nominal taxa that went through a vicariance process at Gondwana, eco-morphologically evolved sympatric with Boidae and offered deeper divergence in the ophidian lineage (Zaher and Smith 2020). The python genera are included under the superfamily Pythonioidea under the family Pythonidae. Pythonidae *sensu stricto* referred to as true python enclave 38 species placed under 11 genera (Uetz et al. 2023). There is one more monotypic family, Loxocemidae having a single species of snake *Loxocemus bicolor* that resembles pythons and has close genetic relatedness (Reynolds et al. 2014; Pyron et al. 2014). The type specimen of Pythonidae is *Coluber molurus* Linnaeus 1758, designated with the taxonomic name *Python molurus* today. By distribution, true pythons are extant in the Eastern hemisphere's tropical and sub-tropical realms except for two species restricted to the Northern hemisphere *P.regius*, and *P.molurus*. The locations include sub-Saharan Africa, South East Asia and Australia (Barker and Barker 2003). Pythonidae was a subject of taxonomic rearrangements, and the recent checklist after taxonomic revisions and phylogenetic recovery includes 38 species (Uetz et al. 2023). Pythons are old-world snakes and are referred to be the descendants of tetrapod that had limbs, and the same is evident with the protruding spurs near the cloacal region of pythons.

1.4 Indian rock pythons

The Indian rock python (Fig.1) is a species under the family Pythonidae that includes true pythons. The Indian rock python (Family: Pythonidae) is widely distributed in India, Sri Lanka and Southeast Asia (Smith 1943; Whitaker 1993; Daniel 2002; Whitaker and Captain 2004). Two subspecies, *P. molurus molurus* (Indian rock python) and *P. molurus bivittatus* (Burmese python) are recognised, and their status as full species was debated (Jacobs et al. 2009). Later, Hunter et al. (2018) analysed samples collected in Florida from morphologically identified Burmese pythons. These samples showed cytochrome oxidase 1 and cytochrome b sequences similar to both Indian rock pythons and Burmese pythons, with high genetic divergences of 5.4% and 4.3%, respectively.

Indian rock python is a larger constrictor snake species known to occur in India, Sri Lanka, Bangladesh, Nepal, Bhutan and Pakistan. In India, their range spans into Tamil Nadu, Kerala, Gujarat, Karnataka, West Bengal, Andhra Pradesh, Orissa, Punjab, Arunachal Pradesh, Assam, Delhi, Jammu - Kashmir, Chhattisgarh, Uttar Pradesh, Bihar, Goa, Assam, Madhya Pradesh, Rajasthan and Meghalaya (Aengals et al. 2021). The Indian rock python is closely recognised with the Burmese python due to their morphological similarities. The Burmese python is differing from the Indian rock python: the top of the body is dark brownish- or yellowish-grey, with a series of 30 to 40 large irregular squarish, black-edged, dark chocolate-grey blotches on the top and sides of the body; it has dark and dark grey dorsal and lateral spots; it has a sub-ocular stripe; and the belly is greyish with dark spots on the outer scale rows (Das 2012). The body is thick and cylindrical; the head is lance-shaped and distinct from the neck; sensory pits can be found in the rostrals as well as on some

supralabials and infralabials (Das 2012). The spurs are small; the tail is short and prehensile; and there are cloacal spurs (Das 2012). The major difference that distinguishes Indian rock python from Burmese python is that the 6th or 7th supralabial scale touches the eye in Indian rock python, whereas in Burmese python, the supralabials are separated from the eye by suboculars (Whitaker and Captain 2004).

The Indian rock pythons are however smaller than the Burmese python. They measure a maximum of 91 kgs in weight and 6.4 m in length (Babar et al. 2019). Indian rock pythons are known to lay eggs as a cluster. The incubation range of pythons ranges between 2 and 3 months (Lederer 1956). Ramesh and Bhupathy, (2010) reported a maximum of 37 eggs in a nest and also estimated to have a hatching rate of 95% in Northern India (Ramesh and Bhupathy 2010). Indian rock pythons are ecologically very poorly studied animals, but based on opportunistic data and relevant studies, they have been known to feed on reptiles, small to medium size mammals and birds (Bhupathy and Vijayan 1989; Bhatt and Choudhury 1993; Ramesh and Bhupathy 2010, Bhupathy et al. 2014).

The Indian rock python is a sit-and-wait predator that used to camouflage in its habitat and attack when the prey was in close proximity. They are known to use terrestrial grounds, water, trees and arboreal environments for thermoregulation and predation (Babar et al. 2019; Vishnu et al. 2024). As a thermoregulatory need, they procure a short hibernation in Northern India (Murphy and Henderson 1997). The Indian rock pythons are known to inhabit burrows of porcupines (*Hystrix indica*) in Bharatpur, India (Bhupathy and Haque 1986; Mukherjee et al. 2017; Mukherjee et al. 2018).

Their feeding ecology is known to be influenced by monthly mean minimum temperature, variation in temperature, and rainfall but was not completely based on prey abundance (Bhupathy et al. 2014).

The feeding ecology of Indian rock pythons was studied by Bhupathy et al. (2014) using tricho-taxonomical techniques at Bharatpur, India. They observed higher feeding incidences during the post-monsoon season (September–November), which could be due to warmer climatic conditions during these months. Tricho-taxonomy, the study of hairs, is of significant importance in researching the dietary habits of carnivores and provides support for controlling the illegal trade of wildlife and its derivatives (Chakraborty and De 2010; Sahajibal et al. 2010).

Due to snake bites, many human casualties have been reported worldwide, which is a primary reason for human-snake confrontation. In the case of the Indian rock python, they face threats not because of their bites but due to their size and fear-inducing body shape, despite being a non-venomous species. This is directed at their plummeting decline across its range (Roshnath and Jayaprasad 2017). Although pythons are known to occur within their natural habitat, they are sometimes known to cross human-dominated areas in search of food and in case of habitat destruction. These encounters conflict scenarios in an urban setup is of conservation priority (Raxworthy and Nussbaum 2000). The coexistence pattern based on people's perceptions is very important for conserving Indian rock python, which can be achieved by rescue and rehabilitation (Khan et al. 2017).

1.5. Spatial ecology in snakes

Spatial ecology is a predominant factor that helps in understanding the population, ethology, home range, and site fidelity of species which helps to devise proper wildlife management, that becomes pivotal for endangered species (Webb and Shine 1997; Chetkiewicz et al. 2006; Durbian et al. 2008; Spencer 2012). Spatial ecology is influenced by a number of constant and changing variables, which may include population, food and water resources, landscape, body size and temperature (Gregory et al. 1987; Macartney et al. 1988; Reinert and Zappalorti 1988; Beier and Noss 1988; Whiting et al. 1997; Chetkiewicz et al. 2006; Waldron et al. 2006; Hoss et al. 2010). Ectothermic species are most influenced by both biotic and abiotic factors, which include climate, thermal values, food resources and prey ethology (Wasko and Sasa 2012; Hoss et al. 2010).

Snakes are an important group that has been widely studied through radio telemetry for understanding their home range, habitat preference and thermal biology, which could be useful for conservation practices (Mullin and Seigal 2011). Radio telemetry studies using transmitters have also shown to be used in the recent past, which should be acknowledged as a drastic development (Sine and Bonnet 2000). Snakes exhibit distinct spatial ecology in terms of habitat differentiation and population variations within close geographic proximity. Understanding both intra-population and inter-population variations is crucial (Rohner et al., 1995; Pétrie and Kempenaers, 1998; Reeve et al., 2009; Gonzales et al., 2020). However, understanding these complex population distributions across vast geographic areas is challenging due to the high expenses, substantial manpower, and requirement of long-term monitoring. These factors pose significant constraints on such research efforts (Gonzales et al. 2020; Natusch et al. 2022).

Spatial ecology in snakes has broadened the hypothesis testing in various aspects. Water snakes have been tested for body size in relation to habitat characteristics and locomotive distance (Gregory 2009). Similarly, the sidewinder snakes have been studied to understand their spatial ecology based on their sex, age, and season (Secor 1994). However, sex-based differences in the movement have conclusive reasons for long movements in mating males and lesser movements for gravid females (Viitanen 1967; Duvall et al. 1985). The differences among individuals thus may have differences in their space use at different seasons, which is, however, not well understood in terms of different species worldwide. This demands the need for understanding the intra-population differences with respect to a species or a population for yearlong (Gregory 2009). The differences in temporal movements with the season, sex and other relevant characteristics would be crucial for identifying the habitat alteration, threats and mortality and thus can approach a systematically scheduled management regime (Seigel and Pilgrim 2002).

While long-term studies on movement ecology have been extensively conducted, shorter-scale studies are also recognized as significant for snakes (Seigel 1993).

A rapid assessment and interpretation of the movement patterns of specific species can be valuable for short-term projects. Such studies have been conducted in various regions worldwide. For instance, a study in Northeastern Brazil focused on the species *Tropidurus hispidus* and *Tropidurus semitaeniatus* by De Andrade Lima et al. (2022). The study observed a total of 25.33 hours of activity and found that *T. semitaeniatus* exhibited noticeably higher mobility compared to *T. hispidus* in terms of short-term movements. Additionally, smaller individuals tended to exhibit a higher

frequency of displacement movements per minute. These studies offer valuable insights for quick interpretations.

The habitat use of snakes can vary seasonally, individually, or by sex, as evidenced by a study on 44 radio-tagged blacksnakes (*Pseudechis porphyriacus*) (Shine 1987). The four-year radio-telemetric study was conducted in New South Wales, revealing unexpectedly high variability in habitat use, activity levels, daily movements, and activity ranges. The study observed significant variation among individual snakes, between sexes, across seasons, years, and study areas. Activity ranges ranged from 0.02 ha to over 40 ha in different snakes, with males exhibiting larger ranges during the mating season (Shine 1987).

A study conducted in Ellenton Bay, South Carolina, observed the home ranges of *Coluber constrictor* snakes. These snakes displayed strictness in maintaining their home ranges, whereas racers from other populations of similar geography or closer proximity exhibited instances of overlapping with other snakes (Plummer and Congdon 1994).

A wide range of snake families has been studied using radio telemetry in different aspects such as the spatial ecology and microhabitat preference of rattlesnakes (*Crotalus horridus*) in southeastern Louisiana; home range and movement ecology of grass snakes (*Natrix natrix*) at Louisiana, USA; habitat suitability of *Hoplocephalus bungaroides* Morton National Park, Southern Sydney (Landreth 1973; Madsen 1984; Webb and Shine 2006; Borgardt 2017). Venomous snakes exhibit complex prey-predatory systems and reproduction-based movements, leading to intricate behavioural strategies and locomotion dynamics. Therefore, studying their movement often necessitates the use of radio telemetry (Glaudas et al. 2017; Tetzlaff et al.

2017). Radio telemetry provides detailed information about habitat dependence, especially for species with high conservation priority due to habitat loss (Vanek and Wasko 2017).

Radio telemetry in snakes has evolved with their range of radio signal transmissions; the technique used during the past decade was mostly using the triangulation and homing method, which demands low cost and higher manpower, offering discrete data. In recent years, technological advancement has pertained to the use of geographical positioning systems, which is costly and demands less manpower to offer continuous data. Older radio-tagging methods in snakes, such as force-feeding and cloacal insertions (Fitch and Shirer 1971), have significant disadvantages. These methods have limited the use of transmitters in smaller snakes and often resulted in casualties for the snakes. However, this has been rectified recently as the transmitters are produced with flexible antennae which also don't compromise the transmission efficiency (Park et al. 2022). The radio transmitters used in 1973 has a signal emission of 0.1 second in 1 second, which was likely to have a maximum receiving signal of 1.5 cm, with a range frequency of 148 MHz (Landreth 1973). The transmitter was 5 cm long, 2 cm diameter and 13.5 g. The recent modifications from Holohil company have a specification of 17 g, 38 mm long and 15 mm diameter, operating with a frequency range of 138-235 MHz (<https://www.holohil.com/transmitters/ai-2/>).

The range distance of VHF (Very High Frequency) radio transmitters has been approximately calculated ≤ 2 with an accuracy of within 10 m area (Silvy 2020).

1.6. Thermal biology of pythons

Temperature is an important variable among poikilotherms, which influences their behaviour and physiology (Tattersall et al. 2012; Huey 1974). Thermoregulation in reptiles is maintained by sensing the fluctuating thermal environment and responding both physiologically and behaviourally in an adaptive manner (Giacometti et al. 2021). Slip and Shine (1988) experimented with the behavioural aspects of thermoregulation in diamond pythons; they concluded the same by conducting experiments on a heatless surface, where they observed an increase in temperature. Indian rock python has been experimentally studied for its thermal biology in diversified aspects in India and across its range. Vinegar (1973) studied two egg clutches, each having 44 eggs laid after a cross-mating session between Burmese python and Indian rock python males and females in an experimental arena to understand the optimal temperature needed for hatching. The results revealed that the hatching success rate totally relied on optimal temperature (30.5°C), and there were differences in the optimal thermal values between different geographical populations. Walsh and Murphy (2003) reported that the ambient temperature needed for hatching Indian rock python eggs ranges between 27°C and 30°C based on a clutch size of 22 eggs. Thermoregulation is mainly maintained through basking in snakes and in that aspect Indian rock pythons were studied on the basis of burrows at the Keoladeo National Park, Rajasthan (Mukherjee et al. 2018). Mukherjee et al. (2018) study identified the threat of basking near the burrows disturbed by tourism. This was alarmingly proposed to affect their breeding and thus could readily reduce their population.

Ramesh and Kamalakannan (2020) studied the thermal profile of the Indian rock python in different seasons of the Keoladeo National Park after Mukherjee et al. (2018). The study concluded that thermoregulation is mainly maintained through basking in snakes, and the incubating females are capable of raising the temperature above ambient level. Due to tourism and disturbance, the basking timing is interrupted, and thus the pythons tend to increase their basking frequency, which negatively affects their lifestyle (Ramesh and Bhupathy 2010, 2013; Bhupathy et al. 2014). Similarly, a study by Vishnu et al. (2024) reported that the body temperature of feeding pythons can be higher than the atmospheric temperature, particularly during the digestion phase. Due to this increased temperature, they may seek out water bodies to regulate their body temperature.

Weather and temperature influence the survival ability of pythons. Stahl et al. (2016) estimated the survival ability of Burmese pythons in Florida using bioenergetics models. Physiological stress induced by lower temperatures during specific seasons (January and December) was observed in the pythons. Lower temperatures pose a survival challenge for invasive Burmese pythons due to the dissimilar geography and their lack of adaptation (Jacobson et al. 2012). Evolutionary processes are driven by various stress factors and are manifested both genotypically and phenotypically before advantageous mutations occur for adaptive evolution. While such mutations traditionally take millions of years to manifest, recent studies have shown rapid evolutionary rates, possibly due to heightened stress levels in the Anthropocene era (Bonnet et al. 2022; Herrel et al. 2008; Sasaki et al. 2009).

Burmese pythons were affected in terms of their survivorship due to low temperatures; they sought refuge inside burrows and available crevices and holes to

tolerate the suboptimal thermal conditions. Over time, they have developed advantageous mutations that aid in thermal adaptations, aligning with a phenomenon known as climate matching, alongside other morphological benefits, as part of a comprehensive adaptive evolution. This process is exemplified within the context of rapid evolutionary changes (Bomford et al. 2009; Castoe et al. 2013; Card et al. 2018).

Table. 1.1. The major studies on Indian rock pythons in India

Authors	Various studies conducted in wild pythons	Place of study
Bhupathy and Vijayan 1989	General ecology	Keoladeo national park, Rajasthan
Bhupathy 1990	Individual identification using blotch pattern	Keoladeo national park, Rajasthan
Bhatt and Choudhary 1993	Diel activity pattern	Keoladeo national park, Rajasthan
Kamalakannan 2009	Diurnal activity	Keoladeo national park, Rajasthan
Ramesh 2010	Ecology of Indian rock python	Keoladeo national park, Rajasthan
Ramesh and Bhupathy 2010	Breeding biology	Keoladeo national park, Rajasthan
Bhupathy et al. 2014	Feeding habits	Keoladeo national park, Rajasthan
Mukharjee et al. 2017	Basking pattern	Keoladeo national park, Rajasthan
Ramesh and Kamalakannan 2020	Activity pattern	Keoladeo national park, Rajasthan
Vishnu et al. 2023	Home range ecology	Moyar river valley, Tamil Nadu
Vishnu et al. 2023	Microhabitat use	Moyar river valley, Tamil Nadu



Fig. 1.1. Indian rock python

2.1. Introduction

Radiotelemetry practices are of utmost importance as they play a crucial role in unravelling the mysteries of snake behaviour, space use, and the intricate secrets and traits of their lives. By employing radiotelemetry techniques, researchers can gain valuable insights that aid in the conservation and management of snake species at the landscape level. The development of this novel radio-telemetry technology has simplified, complicated ecological research much easier. Radio telemetry techniques have been used in wildlife research since the late 1960s (Cochran and Lord 1963). Wildlife radiotelemetry is important in studying animal populations since it allows for improved research outcomes. Radio-telemetry has several applications in research, management, habitat use of animals, and their conservation (Trivelpiece et al. 1986). Telemetry can be helpful in assessing the migratory movements of animals, their preferred route of travel, behavioural responses and survivability, and death (Silvy 2012). Radio telemetry is an advanced method for assessing the snakes' home range, space use, movement, and habitat use. This technology can be helpful in studying cryptic and elusive species. Snakes have been observed to have certain functions and needs in the environment. The snake's activities depend on food capturing, hiding from predation, reproduction, and thermoregulation (Reinert 1993; Weatherhead and Madsen 2009). Snakes maintain or regulate their body temperature during breeding and feeding (Tetzlaff et al. 2017). Snakes have a considerable ecological role in the ecosystem. Still, their population trend seems to be declining due to frequent poaching for skin, collecting venom, mythological beliefs, ophiophobia, and habitat

fragmentation. Snake populations face pressure in the form of habitat loss due to changing land uses (Gibbons et al. 2000; Babar et al. 2019). Therefore, the conservation of snakes is very important to balance the ecosystem. Hence, radio telemetry can be helpful in identifying the unknown habitat specificities and ecological needs of this taxa in the context of management and conservation.

Transmitter implantation in snakes may or may not have drawbacks. Studies have reported that transmitter implantation in snake decreases movement (Knapp and Abarca 2009), reduce reproductive capacity (Godfrey et al. 2003; Reed et al. 2005), and may be fatal (Theuerkauf et al. 2007). Telemetry devices can be placed externally or internally. The external attachments are such as collars, backpacks, and belts (Goodman et al. 2009; Price-Rees and Shine 2011). At the same time, the internal fixing is force feed (Rivas 2001), ingestion of the transmitter or surgical implantation (Fitch and Shirer 1971; Landreth 1973; Reinert and Cundall 1982; Weatherhead and Blouin-Demers 2004), and PIT-tag attachments (Farve 2016). Direct tracking and triangulation methods help the operator locate the tagged animals using VHF or PIT Tag telemetry techniques.

In order to research the Indian rock python, we collected snake telemetry-related literature spanning from 2007 to 2017. The aim was to identify the appropriate transmitter set, manufacturer, radio-tagging method, and optimal anaesthetics for surgical procedures. Additionally, we endeavoured to identify the various snake species worldwide that was studied using radio-telemetry, along with their respective frequencies and IUCN threat statuses during the above-mentioned period. These efforts were undertaken to gather essential information and insights

that would contribute to a comprehensive understanding of the Indian rock python and its conservation needs.

2.2. Materials and methods

The telemetry studies on snakes at global level was collected 10 years from 2007 to 2017. Research articles, published sources, and dissertations were obtained through platforms such as Google Scholar, ResearchGate, and Publish or Perish to gather relevant information. For updating superseded species names and their conservation status, the IUCN web portal and Reptile Database (<https://reptile-database.reptarium.cz/>) were utilised. The number of studies conducted for each species was recorded and compiled in Table. 2.5. In addition, information on the radio transmitters used in the studies and the specific anaesthetics employed during surgical procedures was documented and organised in, Table. 2.2, and Table. 2.3, respectively. Different transmitter attachment methods and possible methods suitable for larger snake species were also noted. The data analysis for this study was conducted using Microsoft Excel.

2.3. Results

2.3.1. Anaesthesia for snake telemetry

Isoflurane is widely used as an anaesthetic agent; by a clear plastic tube, we can deliver the inhalant to the snakes. After administering anaesthesia, we can collect morphological data like SVL, TL, body mass, and sex (Reinert and Cundall 1982; Eric and Vincent 2016). Also, we can record the relaxation of the skeletal muscle, righting reflex loss, tail pinch reflex and tone of the mandibular during the sedation period (Morici et al. 2017). Alfaxalone is also an effective anaesthetising agent that can be administered through intravenous part (Knotek et al. 2013; Knotek 2014;

Knotek 2017). Alfaxalone administration is very effective in snakes via the tail vein. The prescribed dosage of Alfaxalone is 9 mg/kg (Scheelings et al. 2011). Ketamine hydrochloride can be administered through injection, the suggestable concentration is 1.5 mg/kg (Madsen and shine 1996). Halothane or Halo-ethane is also an effective inhalational anaesthesia which was successfully administered in many species (Shine and Fitzgerald 1995; Stanford et al. 2010; Cottone and Bauer 2013; Pierce et al. 2014). Apart from all these sedatives, pain reliever also can be used for transmitter implantation. To reduce pain and swelling, snakes can be injected intramuscularly with Metacam® (meloxicam 0.1 mg/kg) and Baytril® (enrofloxacin 5 mg/kg) 24 h preceding surgeries, at surgery, and 24 h after surgery (Williams et al. 2012).

2.3.2. Transmitter attachments

The first stage of radio telemetry is to capture a snake without causing any harm. Once the snake is captured, a cotton sock should be placed over its head, and the jaws should be closed to prevent any biting (Rivas et al. 1995). Nowadays, there are several methods available for attaching radio transmitters to the body of snakes. The external attachment can be used for short-term movement studies, while surgical implantation techniques are more appropriate for physiological studies. Before and after transmitter attachment or implantation in snakes, certain procedures must be followed as per government wildlife norms, such as anaesthesia immobilization, and post-surgical care. Apart from surgical and surface attachment methods, there was a practice of force-feeding into the stomach or gut (Naulleau 1979; Naulleau and Marques 1973; Reinert 1992). Similarly, other attachments were implantation into the coelomic or abdominal cavity (Reinert

1992; Reinert and Cundall 1982), and subcutaneous implantation (Naulleau 1987; 1989; Plummer and Congdon 1994).

2.3.3.1. External attachment

On skin

Implantation surgeries can be risky for endangered snake species, so the external attachment method is more convenient and safer by comparison (Wylie et al. 2011). The external attachment method is generally used for short-term studies, whereas the implantation process may cause death to the specimen sometimes. However, the external attachment process can also lead to mobility problems and change the natural behaviour of snakes. As a result, frequent observation is necessary (Gent and Spellerberg 1993). In some cases, the size of the snake may be too small for implantation surgery, so external attachment is the best way to carry out the work on smaller specimens (Madrid-Sotelo and García-Aguayo 2008).

Tape attachment

The external attachment method involves attaching the transmitter to the dorsal side of the snake and safeguarding it with tape. This method is generally used for short-term studies and is suitable for semi-aquatic snakes. However, it can cause dermal problems and mobility issues for the snake (Gent and Spellerberg 1993; Wylie et al. 2011).

Glue-only attachment

This Glue-Only method is also an external attachment method for attaching transmitters to snakes. The method involves using a combination of cyanoacrylate glue and colostomy mixture (Nailene Ultra Quick Nail Glue Clear, Aliso Viejo, CA, USA) to paste the bottom of the transmitter onto the snake's skin (Riley et al. 2017).

Subdermal stitch attachment

The subdermal stitch attachment method involves running a sub-dermal catheter and thread under the sub-caudal scales on both sides of the snake's body and then tying the transmitter to the dorsal surface of the snake using the thread (Riley et al. 2017). This method has been proven effective in recent studies in the field and laboratory settings (Riley et al. 2017). The transmitter can be removed once the study is completed, and this method is also suitable for short-term studies. The transmitters attached with glue-only and tape-and-glue methods fell off shortly after placement due to environmental factors and snake shedding (Riley et al. 2017). In contrast, the subdermal stitch method can be long-lasting both in the field and lab and does not cause higher skin irritation (Riley et al. 2017). Although the subdermal stitch method may be a viable external attachment method for radiotelemetry studies in snakes, it may not be suitable for long-term research.

2.3.3.2. Implantation of transmitter

Force-feeding

Force-feeding methods are primitive techniques used in radio-telemetry, where the transmitter is coated with beeswax or put in mineral oil and fed to the snakes by force (Jacob and Painter 1980). This method allows the snake to swallow the transmitter and prevents it from vomiting, but it can cause the transmitter to oscillate between the small intestine and stomach. We can receive signals from the transmitter through a portable radio equipped with a directional antenna, allowing us to triangulate the animal's location. After the study, the transmitter can be forced out of the gastrointestinal tract by mouth or another unit (Landreth 1973). However, this method has ethical concerns and may cause harm to the snake, and

modern techniques such as surgical implantation or external attachment methods are preferred.

Implantation into the coelomic cavity

Implantation of the transmitter into the abdominal cavity just above the sex organs, with the antenna, led subcutaneously towards the head of the snake, is known to be a viable method (Reinert and Cundall 1982). After this implantation, there will be no problems with feeding, growth, or breeding, which can also yield high-quality data on physiological aspects of snakes such as thermoregulation, breeding, developmental studies, behaviour, and movements.

Implantation into the intra- coelomically- cloaca

Transmitters can be placed 20 cm cranial to the cloaca and caudal to the lungs of the snakes. Transmitter antenna wires (20 cm) can be tunnelled subcutaneously and directed caudally using a polypropylene urinary catheter to limit tissue trauma (Hale et al. 2017). In reptiles, intracoelomic implantation of transmitters may lead to pain, inflammation, and infection, while the implantation carries a heavy risk to the life of the specimen (Rudolph et al. 1998; Újvári and Korsós 2000; Lentini et al. 2011).

Subcutaneous implantation

This is a method of transmitter implantation under the skin. The transmitter has to be inserted dorso- laterally in a particular depth of millimetres to the lower third of the snake, and the antenna needs to be fixed in the anterior direction without cutting the tissues of the snakes (Madsen 1984; Naulleau 1987, 1989; Peterson 1987; Újvári and Korsós 1997).

PIT- tag attachment

Passive Integrated Transponder (PIT) tags help scientists track individual organisms by providing a reliable, lifetime "barcode" as a unique identification model, which can offer information at the level of the individual, population, and community (Gibbons and Andrews 2004; Smyth and Nebel 2013). PIT tags vary in size, usually between 10 and 14 millimetres long and about two millimetres in diameter. The glass casing protects the electronic components and prevents tissue irritation. PIT tags are injected with a 12-gauge needle or inserted by surgical incision under the animal's skin, usually into muscle or the body cavity, creating the identity of an individual animal to be determined for the rest of its life by activating the unique alphanumeric code with a PIT tag reader (Gibbons and Andrews 2004). Both external and internal attachment models are available on the market for amphibians and reptiles. In snakes, PIT tags can be placed subcutaneously on the posterior third of the body (Secor 1994; Gibbons and Andrews 2004). Implantable tags are equipped with whip antennas for proper signal coverage (Secor 1994).

Table. 2.1. Types and models of transmitters used in snakes between 2007 and 2017

Types / Model	Weight (g)	Transm. weight/ body weight (%)	Type	Manufacture	Authors
R1655	1.2	1.2	-	Advanced Telemetry Systems, Isanti, MN, USA)	Riley et al. 2017
F1850B	27	<0.6%	-	Advanced Telemetry Systems, Inc.	De la Quintana et al. 2017
SB-2 (10×20 mm)	5.2	NA	-	Holohil radio transmitters (Carp, Ontario)	Akresh et al. 2017
AI-2T Or SI-2T	9, 13.5 or 25	Transmitter not exceed the 5% of the body mass	-	radio transmitter (Holohil Systems Ltd., Carp, Ontario, Canada; models	Hale et al. 2017
SI-2T & SB-T	11,9 & 5	Transmitters did not exceed 4.5% of initial snake body mass	-	Holohil Systems, Carp, Ontario, Canada)	Buchanan et al. 2017
SB- 2T Or SI- 2T,	9,5	Total mass of implanted transmitters and/or loggers never- Exceeded 6% of body mass for a given individual.	Tempert- ure sensitive	Holohil Systems, Ltd., Ontario, Canada)	Tetzlaff et al. 2017
SB-2T Or BD-2T BD-2	5.2, 1.9 1.8	Transmitters were no more than 5% of the snake’s mass at the time of deployment.	Temperatu re sensing	Holohil Systems Ltd., Ontario, Canada)	Sprague 2017
SI-2	13		-	Holohil Ltd., Ontario, Canada)	Glaudas et al. 2017

BD-2T	11	The transmitter mass was no greater than 5% of Each snake's mass.	-	Holohil Inc., Ontario, Canada	Crane et al. 2016
G3		Transmitters Weighed less than 5% of the snake's body mass.	Temperature sensitive	AVM Instrument Company Ltd., CA, USA)	Clark et al. 2016
SI-2T SB-T	11, 9 5	-	Temperature sensitive	Holohil Systems Ltd., Carp, Ontario, Canada)	Buchanan et al. 2017
SI-2T	13	-	Temperature sensitive	Holohil Systems Ltd (Carp, Ontario, Canada)	Goetz et al. 2016
SI-2T	9,11,13	weighed <3% of the snake's total mass	manual and automatic	Holohil Systems Ltd., Carp, ON, Canada)	DeGregorio et al. 2016
R1680	3.6	Which were less than 5% of the snake's total body mass.	-	Advanced Telemetry Systems, Isanti, MN	Howey et al. 2016
SB-2T	5	transmitter never exceeded 2.5 % of a snake's body Mass.	-	(Holohil Systems Ltd., Carp, Ontario	Carter et al. 2016
SB-2 Or SI-2		Implanted packages did not exceed 5% of snake body mass	-	Holohil Systems, Inc., Ottawa	Nordberg and Cobb 2016
SI-2T, SI-2T and SB-T	11, 9,5	Transmitters did not exceed 4.5% of initial snake body mass	Temperature sensitive	Holohil Systems Ltd., Carp, Ontario, Canada)	Putman et al. 2016
SI-2T	-	-	-	Holohil systems Ltd., Carp,	Lind et al. 2008

				Ontario, Canada	
R1650	-	Transmitter mass was less than 2% of snake body mass	-	Advanced Telemetry Systems, Isanti, USA)	Lelièvre et al. 2012
R1535 Or R1520	-	Transmitter mass was, 5% of snake body mass. (400–1000 m reception range)	-	Advanced Telemetry Systems, Inc., North Isanti, MN)	Zappalorti et al. 2015
SI-2, AI-2	11, 25	Transmitter weights did not exceed 0.1% of snake's body mass.	VHF & GPS Tags	Holohil Systems, Ltd., Carp, ON, Canada	Hart et al. 2015
SI-2T	-	Transmitters weighed less than 3% of snake body mass.	Automated	Holohil Systems, Inc., Ontario, Canada	Ward et al. 2013
R1530, R1680		<3 % of the snake's body mass	Automated telemetry	Advanced Telemetry Systems (ATS models]	George et al. 2015
BD-2 NHX and BD2 NHXP (6 × 4 mm)	0.6,1.0 (164 – 165 MHz Reception range)	-	-	Holohil Systems Ltd., Carp, Ontario, Canada	Lardner et al. 2014
SB-2T or SI-2T	5,9	Transmitters weighed, on average, 2.10% of total body weight range: 0.97–3.81%	-	Holohil Systems Ltd., Carp, ON, Canada	Lomas et al. 2015

Table 2.2. Transmitters used for pythons in various studies

Types	Weight(g)	Size (mm)	Frequency (MHz)	Transmitter Weight/Body Weight (%)	Operational life	Reception range (m)	Type	Manufacturers	Authors
SI-2 AI-2	11 25		-	Transmitter weights did not exceed 0.1% of each snake's body mass	9 and 12 months		VHF transmitter	Holohil Systems, Ltd., Carp, ON, Canada.	Hart et al. 2015
SI-2 BD-2	11 5	40_11 mm (14_9.5 mm)	-	0.3% of the pythons' body mass	12 months	0.3–2.9	Temperature-sensitive radio transmitter	Holohil Systems Pty Ltd., Carp, ON, Canada	Corey and Doody 2015
AI-2	25		144-145	Transmitters and data logger weighed less than 0.5% of the total body weight of the pythons	36 months	-	Temperature-sensitive radio transmitter	Holohil Systems Ltd., Canada	Rahman et al. 2014
SB-2T S1-2T S1-2T A1-2T A1-2T	5 11 13.5 16 25	-	-	Based on the individual's body mass	354 ± 290 days	4–1,251	Temperature-sensitive radio transmitter	Holohil Systems Ltd, Ontario, Canada	Bryant et al. 2011
AI-2	-	-	-	-	-	-	Temperature-sensitive Radio transmitter	Holohil Ltd., Carp, Ontario, Canada	Dorcas et al. 2011
SB-2 BD-2G	5 1.85	-	-	<5% of body mass for any individual (2.3–4.4% and 0.8–5.0% of body mass)	18 months	-	Temperature-sensitive radio transmitter	Holohil Pty Ltd, Carp, Canada	Wilson et al. 2006
SI-2T BD-2T	13 or 21 3 & 5	-	-	Transmitters were < 5% of the python's	2-4 years	-	Temperature-sensitive	Holohil Systems Ltd, Carp, Canada	Pearson et al. 2005

or PD-2T				mass			Radio transmitter		
SI-2T	14.5	51-12	-	Transmitter less than 2% of python bodyweight	28 months	-	Temperature-sensitive Radio transmitter	Holohil Systems Pty Ltd, Canada	Heard et al. 2004
TT-IU 1000	40.2±3.65	20	-	Transmitter weight representing 0.9-3.9 % of snake's body mass	10-13 months	-	Temperature-sensitive Radio transmitter	J-Stuart Enterprizes, Grass Valley, California, USA	Slip and Shine 1988
SI-2T TXT-2sm- TT	35 55	45×15 80×18	-	3% of the body mass of the snake	-	600	Temperature-sensitive radiotransmitter	Holohill models	Madsen and Shine 1996
SI-2T	35	45×15	-	Transmitter weighed less than the 4% of the snake's body mass (0.9%).	308 days	32-567	Temperature-sensitive Radio transmitter	Holohill systems. Ontario.	Shine and Fitzgerald 1995
NA	-	70×30	27.2	-	-	90-300	Temperature-sensitive Radio transmitter	Hardin & D. Murdock Department of zoology, University of New England	Johnson et al. 1975

Table. 2.3. Radio transmitter attachment and anaesthesia carried out in several snake species between 2007 and 2017

Authors	Species	Attachment	Anaesthesia
Riley et al. 2017	<i>Pantherophis guttatus</i> <i>Sistrurus catenatus</i> <i>Coluber viridiflavus</i>	Glue attachment,tape and glue attachment,sub dermal stitch attachment	No Anaesthesia
De la Quintana et al. 2017	<i>Eunectes beniensis</i>	Subcutaneous	-
Akresh et al. 2017	<i>Heterodon platirhinos</i>	Abdominal cavities of non-gravid	-
Hileman et al. 2017	<i>Sistrurus catenatus</i>	subcutaneous surgery	-
Hale et al. 2017	<i>Crotalus horridus</i>	Cloaca and caudal to the lung of the snakes	Isoflurane vaporizer anaesthesia
Buchanan et al. 2017	<i>Heterodon platirhinos</i>	Implanted by surgery	-
Vanek and Wasko 2017	<i>Heterodon platirhinos</i>	Implanted by surgery	Enrofloxacin and painkillers (Meloxicam) to snakes at doses based on body weight after surgery
Tetzlaff et al. 2017	<i>Sistrurus catenatus</i>	In to the body cavity	-
Sprague 2017	<i>Thamnophis eques megalops</i>	Surgically implanted & external tape	-
Glaudas et al. 2017	<i>Bitis arietans</i>	Implanted radio-transmitters into the body cavity	-
Crane et al. 2016	<i>Bungarus candidus</i>	Surgically implanted	Vaporized isoflurane
Clark et al. 2016	<i>Crotalus cerastes</i>	Surgically implanted	-
Goetz et al. 2016	<i>Crotalus horridus</i>	Surgically implanted intra peritoneally	Isoflurane anaesthesia
DeGregorio et al. 2016	<i>Pantherophis obsoletus</i> <i>Coluber constrictor</i>	Surgically implanted	-
Howey et al. 2016	<i>Coluber constrictor Priapus</i>	Surgically implanted	-
Carter et al. 2017	<i>Agkistrodon contortrix</i>	Surgically implanted	-
Nordberg et al. 2016	<i>Crotalus horridus</i>	Surgically implanted	Isoflurane inhalant delivered through a clear plastic tube.
Baker et al. 2016	<i>Sistrurus catenatus</i>	Surgically implanted	-

Putman et al. 2016	<i>Crotalus oreganus</i>	Surgically implanted	-
Bauder et al. 2016	<i>Drymarchon couperi</i>	Surgically implanted	-
Lind et al. 2016	<i>Crotalus horridus</i>	Surgically implanted	-
Lelièvre et al. 2012	<i>Hierophis viridiflavus</i> <i>Zamenis longissimus</i>	Surgically implanted in the abdominal cavity of snakes	Isoflurane anaesthesia
Corey and Doody 2016	<i>Morelia spilota</i>	Surgically implanted	-
Zappalorti et al. 2015	<i>Pituophis melanoleucus mugitus</i>	Surgically implanted in the coelomic cavity	-
Hart et al. 2015	<i>Python molurus bivittatus</i>	Surgically implanted intra peritoneally	Isoflurane administered with an anaesthesia machine
Ward et al. 2013	<i>Elaphe obsoleta</i> <i>Pantherophis spp.</i>	Surgically implanted in snakes	-
George et al. 2015	<i>Pantherophis obsoletus</i>	Surgically implanted in snakes	Isoflurane as the anesthetic
Lardner et al. 2014	<i>Boiga irregularis</i>	Surgically implanted in snakes	-
Lomas et al. 2015	<i>Crotalus oreganus oreganus</i>	Surgical intracoelomic implantation	Isoflurane as the anesthetic
Fortney et al. 2012	<i>Coluber constrictor flaviventris</i> <i>Pituophis catenifer sayi</i>	Transmitters were implanted	-
Howze et al. 2015	<i>Coluber flagellum</i>	Surgically implanted	-
Smith et al. 2015	<i>Pituophis m. melanoleucus</i>	Surgically implanted	-
Halstead et al. 2015	<i>Thamnophis gigas</i>	Surgically implanted	-
Cottone and Bauer 2013	<i>Psammophylax rhombeatus rhombeatus</i>	Surgically implanted	Halothane anaesthesia
Pierce et al. 2014	<i>Pituophis ruthveni</i>	Implanted intraperitoneally	Ketamine hydrochloride or halothane
Barve et al. 2013	<i>Ophiophagus hannah</i>	Surgically implanted	-
Barbour and Clark 2012	<i>Crotalus ruber</i> <i>Crotalus oreganus oreganus</i>	Surgically implanted peritoneal cavities	Inhalation anaesthesia (isoflurane)
Maritz and Alexander 2012	<i>Bitis schneideri</i>	External attachment transmitters were glued to the dorsal surface of the snakes using a cyanoacrylate adhesive	Vaporized isoflurane
Howze and Smith	<i>Lampropeltis getula</i>	Surgically implanted	-

2012	<i>getula</i>		
Wittenberg 2012	<i>Crotalus horridus</i>	Surgically implanted	-
Row et al. 2012	<i>Pantherophis gloydi</i>	Surgically implanted	-
Williams et al. 2012	<i>Pituophis catenifer deserticola</i>	Surgically implanted	To reduce pain and swelling, all snakes were injected intramuscularly with Metacam® (meloxicam 0.1 mg/kg) and Baytril® (enrofloxacin 5 mg/kg) 24 h preceding surgeries, at surgery, and 24 h after surgery.
Shew et al. 2012	<i>Pantherophis vulpinus</i>	Surgically implanted	Anesthetized with vaporized isoflurane
MacKinnon et al. 2006	<i>Elaphe gloydi</i>	Surgically implanted	-
Alberto et al. 2011	<i>Natrix tessellata</i>	Surgically implanted	-
Reinert et al. 2011	<i>Crotalus horridus</i>	Surgically implanted	-
Klug et al. 2011	<i>Coluber constrictor flaviventris</i> <i>Pantherophis emoryi</i>	Surgically implanted	-
DeGregorio et al. 2011	<i>Sistrurus catenatus catenatus</i>	Surgically implanted within the peritoneal cavity	-
Wylie et al. 2011	<i>Thamnophis gigas</i>	External transmitter attachment	-
Wylie et al. 2010	<i>Thamnophis gigas</i>	Surgically implanted	-
Corey and Doody 2010	<i>Morelia spilota</i>	Surgically implanted	-
Plummer and Mills 2010	<i>Heterodon platirhino</i>	Surgically implanted	-
Fitzgerald et al. 2010	<i>Hoplocephalus bitorquatus</i>	Transmitters were implanted in the lower peritoneal cavity	-
Anderson 2010	<i>Crotalus horridus</i>	Surgically implanted	Isoflurane gas
Mori and Randriamboavonjy 2010	<i>Leioheterodon madagascariensis</i>	Surgically implanted	-
Harvey and Weatherhead 2010	<i>Sistrurus catenatus</i>	Surgically implanted	-
Wasko and Sasa 2010	<i>Bothrops asper</i>	Surgically implanted	-
Stanford et al. 2010	<i>Nerodia sipedon insularum</i>	Surgically implanted one third anterior to the vent	Isoflurane or halothane

		and loosely sutured them to the body wall.	
Bhaisare et al. 2010	<i>Ophiophagus hannah</i>	Surgically implanted into the coelomic cavity	-
Kapfer et al. 2010	<i>Pituophis catenifer sayi</i>	Surgically implanted	Isoflurane anaesthesia
Steen 2010	<i>Lampropeltis getula</i>	Surgically implanted	-
Camper and Chick 2010	<i>Nerodia fasciata</i>	surgically implanted	Isoflurane that was administered in a clear plastic tube.
Lind et al. 2010	<i>Crotalus oreganus</i>	Surgically implanted	-
Wasko and Sasa 2009	<i>Bothrops asper</i>	surgically implanted in the body cavity	Anesthetized with sevoflurane administered via inhalation
Lagory et al. 2009	<i>Heterodon platirhinos</i>	Surgically implanted	-
Danna and Qualls 2009	<i>Pituophis melanoleucus lodingi</i>	Surgically implanted within the coelomic cavity	-
Camper 2009	<i>Nerodia erythrogaster erythrogaster</i>	Surgically implanted	Anesthetized using isoflurane gas
Steen and Smith 2009	<i>Lampropeltis getula getula</i>	Surgically implanted	-
Brown et al. 2009	<i>Crotalus oreganus</i>	Surgically implanted	Sevoflurane
Sperry et al. 2009	<i>Elaphe obsoleta</i>	Surgically implanted	-
Jackrel and Reinart. 2009	<i>Coluber constrictor Elaphe emoryi</i>	Surgically implanted	-
Freeman et al. 2009	<i>Morelia kinghorni</i>	Surgically implanted in to peritoneal cavity of the snake	-
Radke and Malcom 2009	<i>Senticolis triaspis</i>	Surgically implanted	-
Hyslop et al. 2009	<i>Drymarchon couperi</i>	Transmitters were surgically implanted in the coelomic cavity	-
Brito 2003	<i>Vipera latastei</i>	Surgically implanted	-
Smith et al. 2009	<i>Agkistrodon contortrix</i>	Surgically implanted	-
Foster et al. 2009	<i>Elaphe spiloides</i>	Surgically implanted	-
Gardner-Santana and Beaupre 2009	<i>Crotalus horridus</i>	Surgically implanted	-
Madrid-Sotelo and García-Aguayo 2008	<i>Oxybelis aeneus</i>	Transmitters were externally attached by using glue and tape.	-
Beaupre 2008	<i>Crotalus horridus</i>	Surgically implanted	-

Carfagno and Weatherhead 2008	<i>Elaphe obsoleta</i> <i>Coluber constrictor</i>	Surgically implanted	-
Kapfer et al. 2008	<i>Pituophis catenifer sayi</i>	Surgically implanted	Isoflurane anaesthesia
Waldron et al. 2008	<i>Crotalus adamanteus</i>	Surgically implanted	Injectable anaesthesia (i.e., Ketamine)
Sperry and Taylor 2008	<i>Elaphe guttata emoryi</i>	Surgically implanted in to the body cavity	Anesthetized using isoflurane gas
Cottone and Bauer 2008	<i>Psammophylax rhombeatus rhombeatus</i>	Surgically implanted	-
Wisler et al. 2008	<i>Natrix natrix</i>	Surgically implanted into the body cavity through a small vertical incision of about 15 mm laterally in the posterior third of the snake	-
Pattishall and Cundall 2008	<i>Nerodia sipedon</i>	Surgically implanted	-
Kapfer et al. 2008	<i>Pituophis catenifer sayi</i>	Surgically implanted into the coelomic cavity	Anesthetized
Crane and Greene 2008	<i>Agkistrodon piscivorus</i>	Surgically implanted	Anesthetized with vaporized isoflurane while being restrained in an induction tube
Tozetti and Martins 2007	<i>Crotalus durissus</i>	Transmitter attached externally	-
Wund et al. 2007	<i>Lampropeltis getula getula</i>	Surgically implanted	-
Blouin-Demers et al. 2007	<i>Elaphe obsoleta</i>	Surgically implanted	Isoflurane anaesthesia
Jellen and Kowalski 2007	<i>Sistrurus catenatus</i>	Surgically implanted & externally attached	-
Johnson et al. 2007	<i>Masticophis flagellum</i>	Implanted subcutaneously	-
Tanaka 2007	<i>Elaphe quadrivirgata</i>	Surgically implanted	-
Koenig et al. 2007	<i>Epicrates inornatus</i>	Surgically implanted into the body	-

Table. 2.4. Radio transmitter attachment and anaesthesia practices carried out in pythons

Sl.no	species	Common name	Authors	Transmitter attachment	Anaesthesia
1	<i>Python molorus bivittatus</i>	Burmese python	Hart et al. 2015	Radio transmitter was implanted intraperitoneally	Isoflurane administered with an anaesthesia machine; the surgery lasted between 30 to 60 min for each snake
2	<i>Morelia spilota</i>	Carpet python	Corey and Doody 2015	-	-
3	<i>Python molorus bivittatus</i>	Burmese python	Rahman et al. 2014	Surgically implanted in the coelomic cavity of pythons	-
4	<i>Morelia spilota imbricata</i>	South-west Carpet python	Bryant et al. 2012	Implanted with temperature-sensitive radio-transmitters	-
5	<i>Python molorus bivittatus</i>	Burmese pythons	Dorcas et al. 2011	-	-
6	<i>Morelia spilota</i>	Carpet python	Corey and Doody 2010	Surgically implanted	-
7	<i>Morelia viridis</i>	Green tree python	Wilson et al. 2006	Surgically implanted	-
8	<i>Morelia spilota imbricata</i>	South-west Carpet python	Pearson et al. 2005	Transmitter and aerial were being inserted into the peritoneum	Isoflurane
9	<i>Morelia spilota metcalfei</i>		Heard et al. 2004	Surgically implanted	-
10	<i>Morelia spilota spilota</i>	Diamond python	David and Shine 1988	Surgically implanted	-
11	<i>Liasis fuscus</i>	Water python	Madsen and Shine 1996	Surgically implanted in the peritoneal cavity	Snakes were anesthetized by intraperitoneal injection of ketamine hydrochloride (1.5 mg/kg)
12	<i>Morelia spilota</i>	Carpet python	Shine and Fitzgerald 1995	Surgically implanted	Halo-ethane inhalational anaesthesia
13	<i>Morelia spilota spilota</i>	Diamond python	Slip and shine 1988	-	-
14	<i>Aspidites melanocephalus</i>	Black-headed rock python	Johnson et al. 1975	Force – fed	No Anaesthesia

Table. 2.5. Frequency-wise radiotelemetry studies conducted in snakes with the latest IUCN names and status (2007-2017)

Sl.no	Species	Common Name	Family Name	IUCN Status	No. of studies conducted	Continent/ or location
1	<i>Zamenis longissimus</i>	Aesculapian Ratsnake	Colubridae	LC	1	Europe
2	<i>Vipera latastei</i>	Lataste's Viper	Viperidae	VU	1	Europe
3	<i>Thamnophis gigas</i>	Giant Garter Snake	Natricidae	VU	3	North America
4	<i>Thamnophis eques</i>	NA	Natricidae	LC	1	North America
5	<i>Sistrurus catenatus</i>	NA	Viperidae	LC	8	North America
6	<i>Senticolis triaspis</i>	Green Rat Snake	Colubridae	LC	1	North & Middle America
7	<i>Python bivittatus</i>	Burmese Python	Pythonidae	VU	4	North America & Asia
8	<i>Psammophylax rhombeatus</i>	Spotted Skaapsteker	Psammophiidae	LC	2	Africa
9	<i>Pituophis ruthveni</i>	NA	Colubridae	EN	1	North America
10	<i>Pituophis melanoleucus</i>	NA	Colubridae	LC	3	North America
11	<i>Pituophis catenifer</i>	Gopher Snake	Colubridae	LC	5	North America
12	<i>Pantherophis vulpinus</i>	Eastern Fox Snake	Colubridae	LC	1	North America
13	<i>Pantherophis spiloides</i>	Midland Rat Snake	Colubridae	LC	2	North America
14	<i>Pantherophis obsoletus</i>	Western Rat Snake	Colubridae	LC	6	North America
15	<i>Pantherophis guttatus</i>	Red Cornsnake	Colubridae	LC	1	North America
16	<i>Pantherophis gloydi</i>	Eastern Fox Snake	Colubridae	LC	2	North America
17	<i>Pantherophis emoryi</i>	NA	Colubridae	LC	3	North America
18	<i>Oxybelis aeneus</i>	Brown Vinesnake	Colubridae	LC	1	South & Middle America
19	<i>Ophiophagus Hannah</i>	King Cobra	Elapidae	VU	2	Asia
20	<i>Nerodia sipedon</i>	NA	Natricidae	LC	2	North America
21	<i>Nerodia fasciata</i>	NA	Natricidae	LC	1	North America
22	<i>Nerodia erythrogaster</i>	NA	Natricidae	LC	1	North America
23	<i>Natrix tessellate</i>	Dice Snake	Natricidae	LC	1	Asia, Africa & Europe
24	<i>Natrix natrix</i>	Grass Snake	Natricidae	LC	1	Europe & Asia
25	<i>Morelia spilota</i>	Carpet Python	Pythonidae	LC	9	Australia
26	<i>Simalia kinghorni</i>	Scrub Python	Pythonidae	NE	1	Australia
27	<i>Masticophis flagellum</i>	NA	Colubridae	LC	2	North America
28	<i>Leioheterodon madagascariensis</i>	Malagasy Giant Hognose Snake	Pseudoxyrhophiidae	LC	1	Africa
29	<i>Lampropeltis getula</i>	Common Kingsnake	Colubridae	LC	4	North America
30	<i>Hoplocephalus bitorquatus</i>	Pale-headed Snake	Elapidae	LC	1	Australia

31	<i>Hierophis viridiflavus</i>	Western Whip Snake	Colubridae	LC	2	Europe
32	<i>Heterodon platirhinos</i>	NA	Dipsadidae	LC	4	North America
33	<i>Eunectes beniensis</i>	NA	Boidae	LC	1	South America
34	<i>Epicrates inornatus</i>	Puerto Rican Boa	Boidae	LC	1	Caribbean Sea
35	<i>Elaphe quadrivirgata</i>	Japanese Four-lined Ratsnake	Colubridae	LC	1	Asia
36	<i>Drymarchon couperi</i>	NA	Colubridae	LC	2	North America
37	<i>Crotalus ruber</i>	NA	Viperidae	LC	1	North America
38	<i>Crotalus oreganus</i>	NA	Viperidae	LC	5	North America
39	<i>Crotalus horridus</i>	Timber Rattlesnake	Viperidae	LC	9	North America
40	<i>Crotalus durissus</i>	Cascabel Rattlesnake	Viperidae	LC	1	South America
41	<i>Crotalus cerastes</i>	NA	Viperidae	LC	1	North America
42	<i>Crotalus adamanteus</i>	NA	Viperidae	LC	1	North America
43	<i>Coluber constrictor</i>	NA	Colubridae	LC	6	Middle America
44	<i>Bungarus candidus</i>	Malayan Krait	Elapidae	LC	1	Asia
45	<i>Bothrops asper</i>	Terciopelo	Viperidae	LC	2	Middle & South America
46	<i>Boiga irregularis</i>	Brown Tree Snake	Colubridae	LC	1	Australia
47	<i>Bitis schneideri</i>	Namaqua Dwarf Adder	Viperidae	LC	1	Africa
48	<i>Bitis arietans</i>	Puff Adder	Viperidae	LC	1	Africa
49	<i>Agkistrodon piscivorus</i>	NA	Viperidae	LC	1	North America
50	<i>Agkistrodon contortrix</i>	NA	Viperidae	LC	2	North America
51	<i>Morelia viridis</i>	Green Tree Python	Pythonidae	LC	1	Australia
52	<i>Liasis fuscus</i>	Water Python	Pythonidae	LC	1	Australia
53	<i>Aspidites melanocephalus</i>	Black-headed Python	Pythonidae	LC	1	Australia

A total of 54 snake species were used for telemetry studies between 2007 and 2017, consisting of 33 genera and 9 families. The maximum number of studies were conducted in the family Colubridae (36%), followed by Viperidae (24%). The remaining families have a proportion of Natricidae 13 %, Pythonidae 11 %, Elapidae 6 %, Boidae 4 %, and Pseudoxyrhopiidae, Dipsadidae, Psammophidae 2% each (Fig.2.1). Among them, 2% are endangered, 7% are vulnerable, and 2% are not evaluated (Fig.2.2). Most of the studies were conducted in the North American Continent, particularly in the United States (n= 28). Only three studies were conducted in the Asian continent.

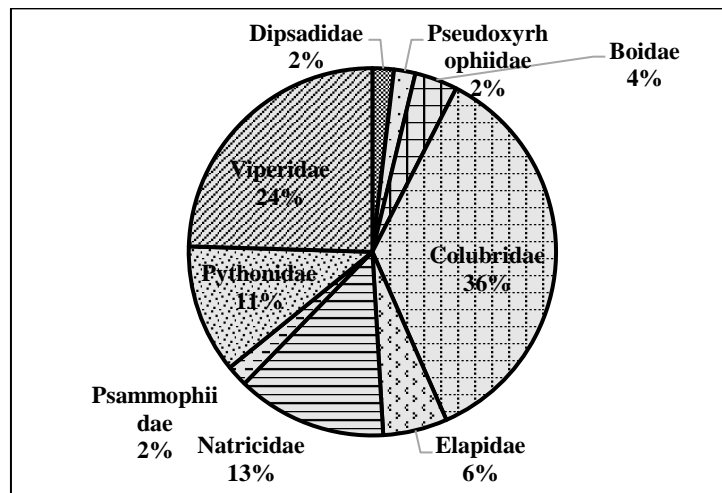


Fig. 2.1. The proportion of family-wise radiotelemetry studies conducted in snakes (2007-2017)

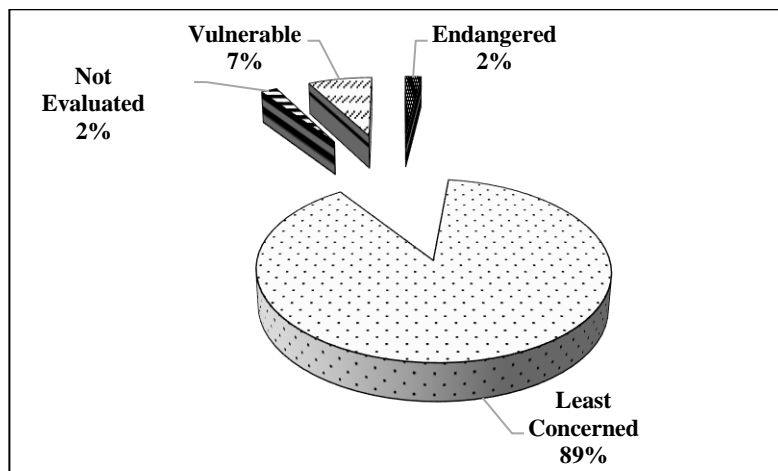


Fig. 2. 2. The proportion of IUCN status-wise radiotelemetry studies conducted in snakes (2007-2017)

Selection of radio-transmitters for the study

The selection procedure for radio telemetry equipment is completely based on the studies conducted in the previous years on the size, behaviour, and life history of the species which gives quality data and reduces impacts (Ministry of Environment Report 1998). For short-term studies, surface transmitter attachment is the best method in snakes. Short-term studies are less than six months, whereas long-term studies extend for more than one year. Implantable radio transmitters have a maximum battery capacity of 2 to 3 years.

For long-term studies, internal implantation will be effective. In the case of implantation of the transmitter in the body of snakes may lead to the formation of inflammation or infection (Shine and Lambeck 1985). Pioneer studies on the subcutaneous implantation of stiff antennas have caused many complications, but currently, more flexible types are available in the market, which has less impact on the snake.

Surgical implantation may affect the feeding habit of snakes and reduces the growth and chance of reproduction, it may cause the decreased consumption of food which leads to severe health problems in the snakes (Weatherhead and Blouin-Demers 2004; Lentini et al. 2011), and corticosterone (stress) levels will not significantly increase by the implantation of a transmitter (Sperry et al. 2009). Weatherhead and Blouin-Demers 2004 reported that a rigid transmitter in the body cavity and a flexible antenna running under the skin could affect a snake's constricting ability, ultimately impacting its feeding habits.

However, advanced transmitters can be helpful in reducing the infection, which have been coated with multiple layers of a biologically inert butyl rubber

compound and antenna covered with a clear Teflon coating, and, the clear silicone tubing reinforces the base (<https://www.holohil.com/transmitters/ai-2/>).

To collect simple physiological parameters like mobility and home range assessment an inexpensive transmitter is enough. But in the case of monitoring the body temperature and certain physiological records, we need to have the support of advanced transmitters (Újvári and Korsós 2000). The most suitable VHF implants for our study are AI-2 Holohil models (Holohil Systems Ltd., Carp, Ontario, Canada) (Fig. 2.3) in the recent years many studies have used this transmitters (DeGregorio et al. 2016; Buchanan et al. 2017; Glaudas et al. 2017).

Why AI-2 Holohil models?

From the previous studies, we found that the VHF implantable AI-2 models are best for long-term studies in Indian rock python due to their body plan (Smith et al. 2021) and inexpensive in comparison with GPS tags. These units have been prepared for intraperitoneal implantation in snakes and lizards. When fitted with a temperature sensor, the pulse rate is adjusted to accommodate the wide-body temperature range in poikilotherms.

Table. 2.6. Specifications of the AI-2 VHF transmitter

Model	Weight	Standard Life	Lifespan range	Dimensions: L x Diameter (mm)
AI-2	17g	24 months	12-30 months	38 x 15
AI-2	28g	36 months	24-60 months	46 x 17



Fig. 2.3. Implantable VHF radio-transmitter (AI-2 Holohill model)

The frequency range of the transmitter is 138 – 235 MHz, and the transmitter has been designed as a crystal-controlled two-stage setup and pulsed by a CMOS multivibrator—the pulse width is standard at the rate of 24 milliseconds. Also, have the standard pulse rate which is 35 pulses per minute (ppm) and it is available from 20-120ppm. The power output has been set to use available battery power over the required transmitter life. The activation of the transmitter is by removing an external magnet that starts the transmitter, and replacing the magnet stops the functioning of the transmitter.

The housing of the transmitter: The transmitter and battery are hermetically covered by a brass case. A small groove is added to the unit to allow for suturing during implantation. To prevent tissue reactions, the case has been coated with many layers of a biologically inert butyl rubber compound. The transmitter's antenna is a finely stranded stainless-steel cable, enclosed with a clear Teflon coating. Clear silicone tubing reinforces the base.

2.4. Conclusion

Based on reviewing the telemetry studies conducted between 2007 and 2017, several key findings emerged. Firstly, a total of 54 snake species were utilized for these studies, representing 33 genera and 9 families. It is noteworthy that among the species studied, 2% were classified as endangered, 7% as vulnerable, and 2% had not been evaluated for conservation status. Geographically, the majority of the studies were conducted in North America, particularly in the United States, with a

total of 28 studies taking place in this region. Only 3 studies were conducted in the Asian continent between 2007 and 2017.

These findings highlight the disproportionate focus on certain snake families in telemetry studies, with Colubridae and Viperidae being the most extensively studied. It also indicates the need for increased research efforts in other families and continents to gain a more comprehensive understanding of snake behavior and ecology. Additionally, the presence of endangered and vulnerable species in the study sample underscores the importance of conducting telemetry studies to inform conservation efforts and mitigate threats to snake populations.

Based on the literature review, we identified transmitter implantation as the suitable transmitter attachment method for Indian rock python. Also, it was found that the VHF AI-2 Holohil model (Fig. 2.3) was the best transmitter for the study due to the animal's body plan, whereas Isoflurane gaseous anaesthesia is considered suitable anaesthetic agent.

The study was undertaken in a landscape connecting the Mudumalai Tiger Reserve with the Satyamangalam Tiger Reserve, through the Moyar valley, also called the Moyar canyon. Moyar valley enclaves under the Segur plateau, Nilgiri plateau, Mysore plateau and Thalamalai plateau. The Segur plateau is an ecologically distinctive region of the Mudumalai Tiger Reserve as the region conjuncts the Western ghats with the Eastern ghats. The Mysore plateau extends into the state of Karnataka. Geographically the Segur and Mysore plateaus are found west to north of Moyar Valley. The Segur plateau and Mysore plateau are separated by a 260 m gorge (Fig. 3.1), referred to commonly as the Moyar gorge. The Thalamalai plateau is found in the northeast region of Moyar Valley, which is protected under the Satyamangalam Tiger Reserve. At the same time, the eastern extension falls under the Coimbatore division of Tamil Nadu. The Nilgiri plateau is formed in the southwestern region of Moyar valley. The landscape is also called the Nilgiri hills, which is formed at a higher altitude comprising mostly of southern tropical montane forest, also infamously called Sholas and montane grassland. They usually coexist together, and so the landscape is undulating with grasslands and in between the valleys of sholas are found. They are usually called shola montane grassland mosaics. The Moyar gorge is the longest, deepest, and oldest gorge in peninsular India (Lal 2016). The length is 22 km, 260 meters deep, and about 2.5 billion years old. While the Moyar river is a tributary of River Bhavani, in southern India, which originates from a small village called Mayar or Moyar near Masinagudi (Krishnan and Ramasamy 2022).



Fig. 3.1. Moyar River Gorge, Mudumalai Tiger Reserve



Fig. 3.2. A view of Moyar River Valley

3.1. Mudumalai Tiger Reserve

The Mudumalai Tiger Reserve is found in the tri-junction of Tamil Nadu, Kerala, and Karnataka (Fig.3.3). The reserve was initially a wildlife sanctuary. Then, due to the Tiger population and its co-predators, it was later notified and declared as a tiger reserve. It comprises different kinds of vegetation like Moist deciduous, Dry deciduous, Scrub jungle, Semi-evergreen, Riparian Forest, and Vayals (swamp ecosystem). There were five ranges initially comprising 321 Km², which was revised and classified as eight ranges, comprising an additional 367.59 km² (buffer) along with 321 km² (core area), totalling to 688.59 km². The reserve borders many other Protected Areas like Wayanad wildlife sanctuary, Bandipur tiger reserve, Nilgiri hills, Mukurthi national park, Gudalur forest division, Satyamangalam tiger reserve, Bilgiri rangan hills and Cauvery wildlife sanctuary. There are primitive forest dwellers like Irulas, Kurumbas and Paniyas. The major wildlife species are elephant, tiger, leopard, hyena, wild dog, spotted deer, Indian gaur, four-horned antelope, barking deer, sambar deer, mouse deer, and sloth bear.

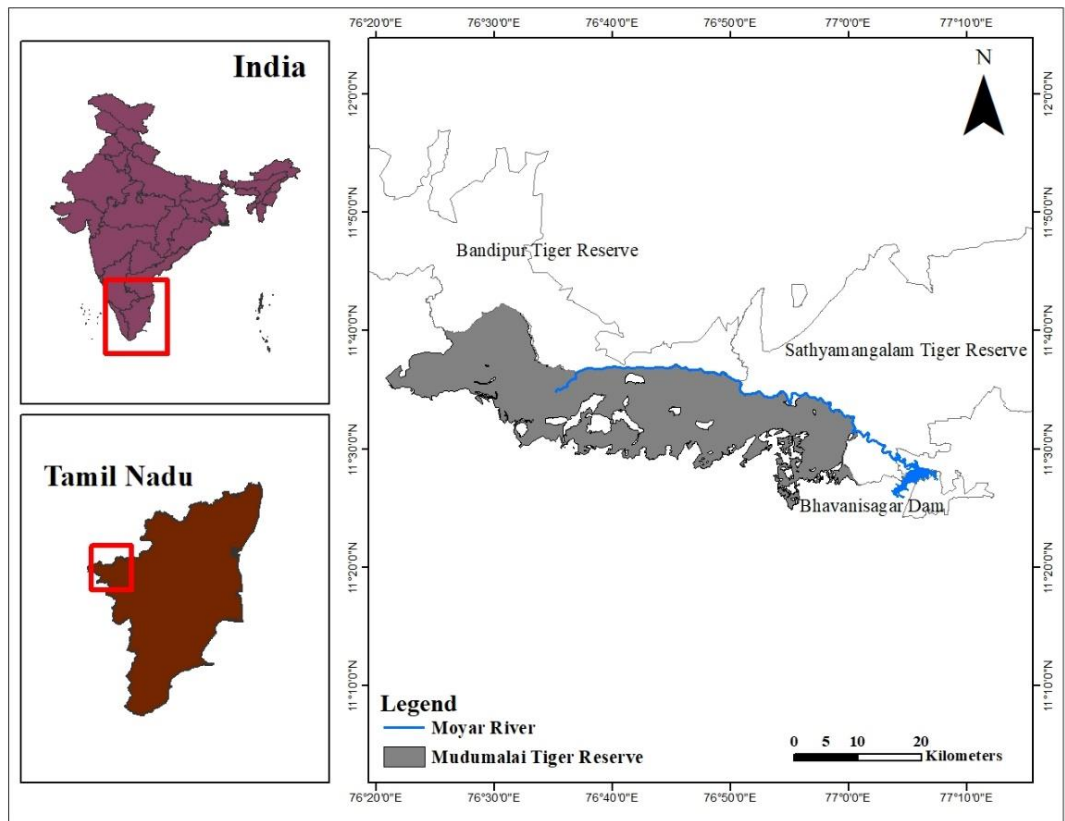


Fig.3.3. Mudumalai Tiger Reserve

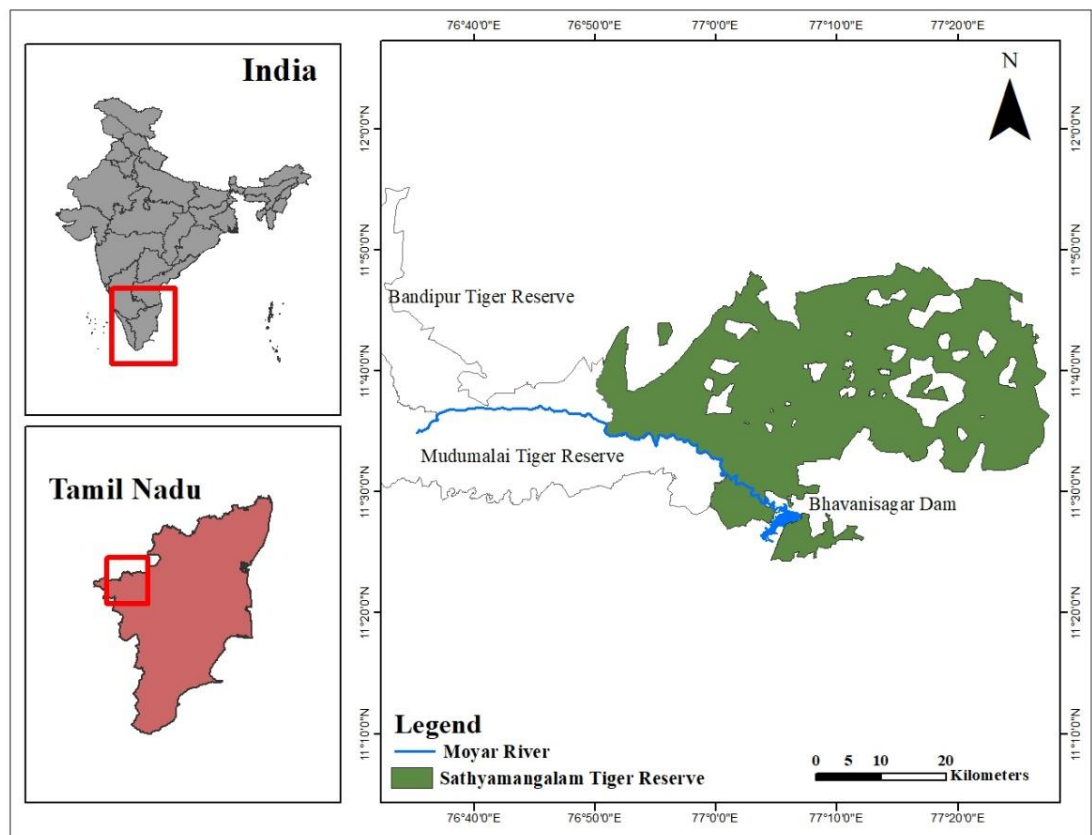


Fig. 3.4. Sathyamangalam Tiger Reserve

3.2. Sathyamangalam Tiger Reserve

The Sathyamangalam tiger reserve (Fig.3.4) is contiguous with Mudumalai tiger reserve, where the Moyar river enters from Mudumalai. The reserve comes under the Erode district, comprising a total forest area of 1408.405 km², of which core area is 793.493 km², and the buffer area is 614.912 km². The contiguity also forms an important corridor leading to Mudumalai, which is also called the Great Moyar corridor. The corridor is connected with Mudumalai through the Moyar valley at certain places like Mangalapetti, Thengumarahada, Gajalatti, Kallam palayam, Patramangalam, Karachikorai etc. The reserve includes several habitats similar to the Mudumalai tiger reserve.

The study area, including both the tiger reserves, falls under the Nilgiri biosphere reserve, which also connects the Eastern and Western ghats. The landscape consists of many tiger blocks, which also serve as a main elephant corridor. The ecosystem, with its altitude and both biotic and abiotic factors, presents a rich showcase of biodiversity. The reptilian studies in the Moyar River Valley (MRV) are, however, scanty in comparison with other vertebrate studies; very few reptile studies have been done in this region which includes; Das et al. (2014); Baranidharan et al. (2019); Ramesh et al. (2019); Thirumurugan et al. (2020); Samson et al. (2021); Vishnu and Ramesh (2021); Vishnu et al. (2021), Khanduri et al. (2022); Vishnu et al. (2023) and Vishnu et al. (2024). The riparian forest is one of the primary habitats in the Moyar valley, and on either side of the river has a spacious area with lots of fallen logs and thickets, which is an essential habitat for reptiles. For larger snakes like Indian rock pythons, the riparian habitat is very important as the space and availability of water sources accomplish their ecological needs. The Moyar

river valley has magnificent trees along the riparian habitat, which has proved a potential landscape for vultures thriving there. There are four species of vultures recorded from this landscape such as white-rumped vulture (*Gyps bengalensis*), Red-headed vulture (*Sarcogyps calvus*), Long billed Indian vulture (*Gyps indicus*) and Egyptian vulture (*Vulture percnopterus*) (Samson et al. 2018). The species are known to inhabit or roost on the *Terminalia arjuna* tree, which is predominantly found throughout the river valley. The above three are critically endangered, while the Egyptian vulture is endangered (Samson et al. 2018). The Moyar river also has a good population of Mugger crocodiles (*Crocodylus palustris*) (Whitaker 2015) and the endemic mahseer fish species *Tor moyarensis* and *Tor remadevii* (WWF 2013).

3.3. Moyar Valley Landscape

The study site is an important link between the protected area landscapes which may also have genetic links making different meta-populations in the wild animal community. The diversified habitats, vegetation, and taxa incorporate to make the study area a biodiversity-rich zone, and also hotspot for conservation aspects. The study area is nested in between the slopes of grassy savannah vegetation with stunted trees (Fig.3.2). The river being the separator has a unique bioclimatic environment when compared to other parts of the two reserves. The study area provides the main source of water for both the reserves as well as for people residing in the state of Tamil Nadu and Karnataka. Both the reserves share a similar ecosystem regarding vegetation, wildlife taxa, and management.

3.4. Elevation

The elevation of both the Sathyamangalam and Mudumalai Tiger Reserves are ranging from 227 meters to 2198 meters (Fig.3.5). The digital elevation map has been prepared by using Arc GIS 10.8.2 Version. The elevation data has been

obtained from the ASTER GDEM—the Mudumalai wildlife sanctuary and national park is located in the Nilgiri hills in the state of Tamil Nadu, India. It is situated at an elevation ranging from 960 to 2,266 meters above sea level (MSL) (Ramesh et al. 2012).

3.5. Climate

The study sites experience three major seasons: Monsoon (August - November), Post-monsoon (December - March), and Summer (April-July) (Venkitachalam and Senthilnathan 2016). The region's rainfall has been reported to be 850 mm, and the temperature of the area has been reported to range between 21°C and 28°C by Rajput et al. (2019).

3.6. Landcover

The land cover composition of the Mudumali and Sathyamangalam tiger reserves consists of trees, scrub forest, croplands, builtup areas, and water bodies (Fig.3.6). However, the entire valley region is covered with scrub forest patches. The trees are the landcover class composed of various forest types excluding scrub forest patches.

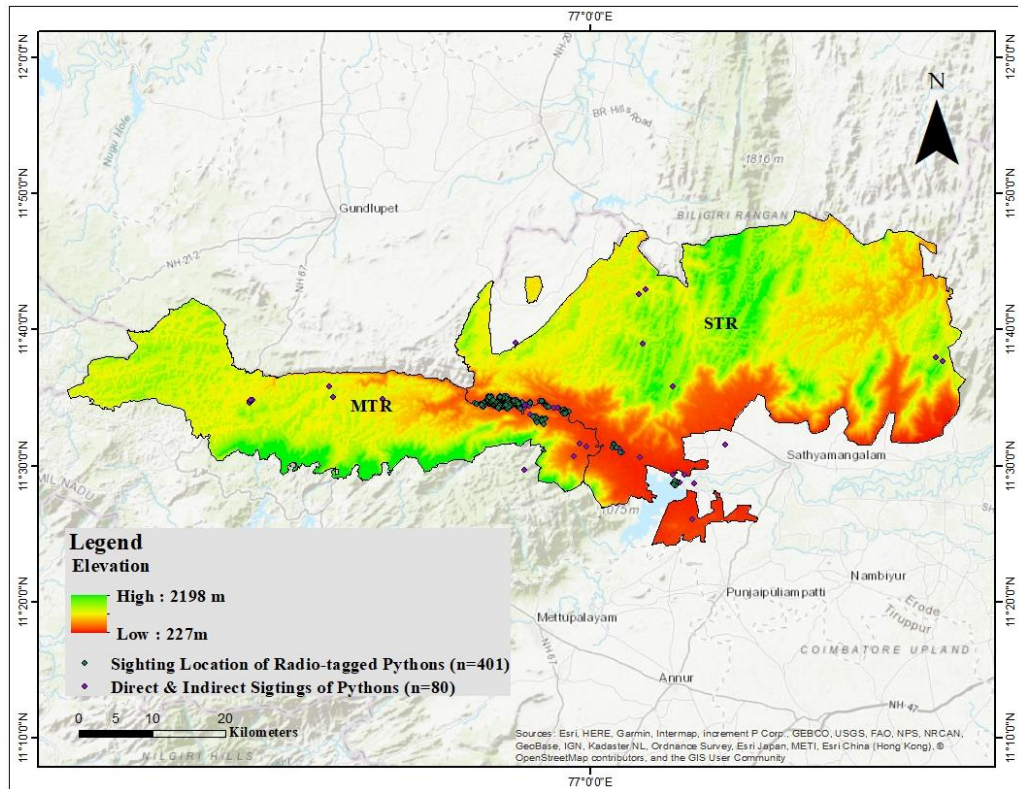


Fig. 3.5. Python detection locations in the different elevation ranges of the Sathyamangalam and Mudumalai Tiger Reserves, Tamil Nadu, India

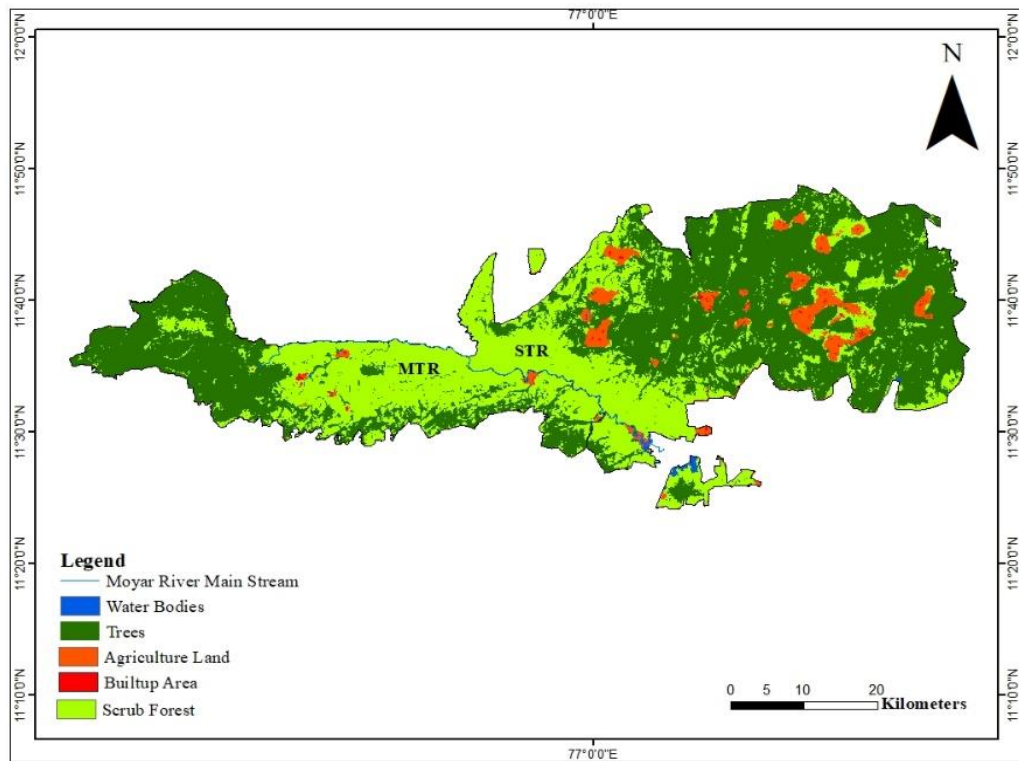


Fig. 3.6. Land use and land cover (LULC) map of the Sathyamangalam and Mudumalai tiger reserves, Tamil Nadu, India

3.7. Precipitation

According to Krishnan and Ramasamy (2022), the rainfall in the lowland area of Moyar river valley is recorded as 700 mm, while in the upper land, it was nearly 3000 mm. However, Rajput et al. (2019) reported that the rainfall of this region is around 850 mm.

3.8. Temperature

The Moyar valley region is positioned in a tropical climatic belt. However, it is experiencing hot weather in comparison with the nearby Nilgiri hills. Krishnan and Ramasamy (2022) report the annual average temperature in the valley as 30°C, with a minimum average temperature of 18°C. In contrast, Rajput et al. (2019) have reported that the temperatures in this valley region range between 21°C and 28°C.

The present study's readings obtained from the field-deployed Hobotemp data logger observed that the minimum temperature was 12.48 °C in the month of January, and the maximum was 38.92 °C in April. Furthermore, the mean minimum monthly temperature observed in the Moyar river valley for the month of January was 23.03°C, while the maximum monthly mean temperature was recorded in April at 30.73°C (Fig.3.7).

3.9. Relative humidity

The present study observed that the minimum relative humidity was 12.004% in the month of February, and the maximum was observed at 100%, for several months. Additionally, the mean minimum monthly relative humidity observed in March was 48.19%, while the maximum mean monthly relative humidity was recorded in October at 92.27% (Fig. 3.7).

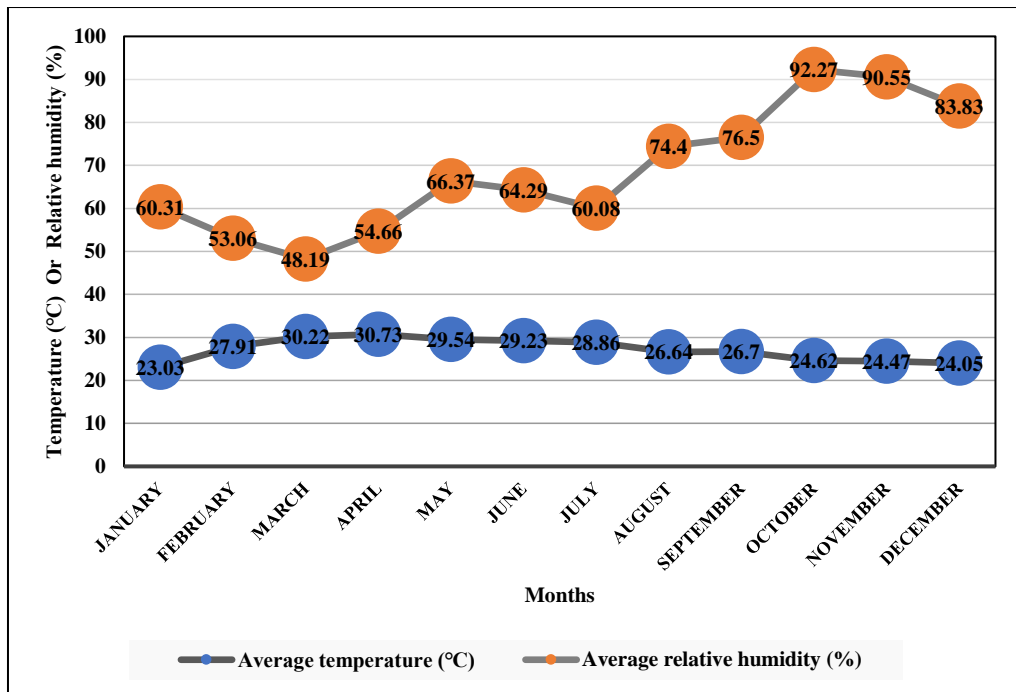


Fig. 3.7. Average monthly temperature and relative humidity in the Moyar river valley for the year 2019

3.10. Initial field surveys

To estimate the home ranges and homing instinct of Indian rock pythons, a study was initiated at the Moyar river valley, which is a portion of the Sathyamangalam and Mudumalai tiger reserves. From 2017 to 2018, reccy surveys and transect walks on the different parts of the tiger reserves to identify the python locations was done.

One km line transects surveys were done for the vegetation assessment. A total of 50m transects were done between 2017 and 2018. The one km transects were laid in five major forest types of Sathyamangalam and Muduamalai tiger reserves. Along one km transect ten quadrates of 10 m x 10 m, were laid at every 100 meters distance (Fig. 3.8). Further, intensive searches were carried out to find live python individuals and secondary evidence on each corner of the quadrates, such as shed

skins, scats, and tracks of movement. The microhabitats inside the quadrates, such as rock crevices, termite mounds, burrows, tree hollows, water bodies, bushes, and debris, were carefully observed. The direct sightings (live individuals, movement tracks, shed skin) and indirect sightings (by location from villagers, forest staff, and researchers) were plotted on the map as python detection locations (Fig. 3.9).

The line transects were ineffective in locating pythons; therefore, we opted for opportunistic survey methods. We only found one pair of live individuals from 50 line transects conducted throughout the tiger reserves. Therefore, we focused on the river valley regions for opportunistic field surveys, which is one of the most appropriate surveys for searching pythons, and it was supported by various published literature sources (Freeman 2009; Rahman et al. 2014; Hart et al. 2015; Smith et al. 2021; Bartoszek et al. 2021). However, 80 individual locations were obtained throughout the study area (Fig. 3.8).

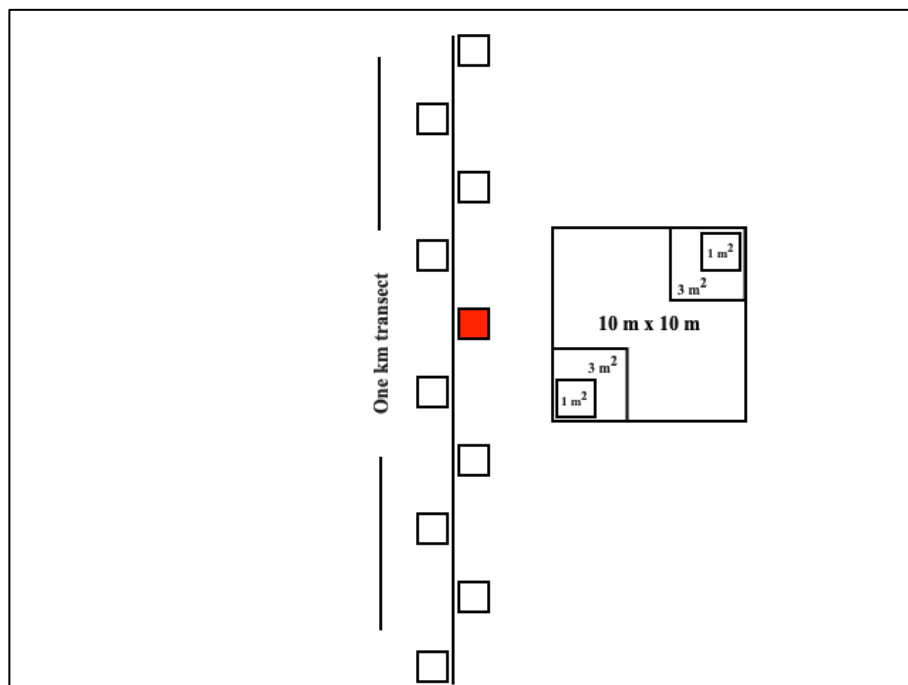


Fig. 3.8. Schematic sketch of the sample design used to survey the tree vegetation in five major Moyar river valley landscape forest types in the Sathyamangalam and Mudumalai tiger reserve, southern India.

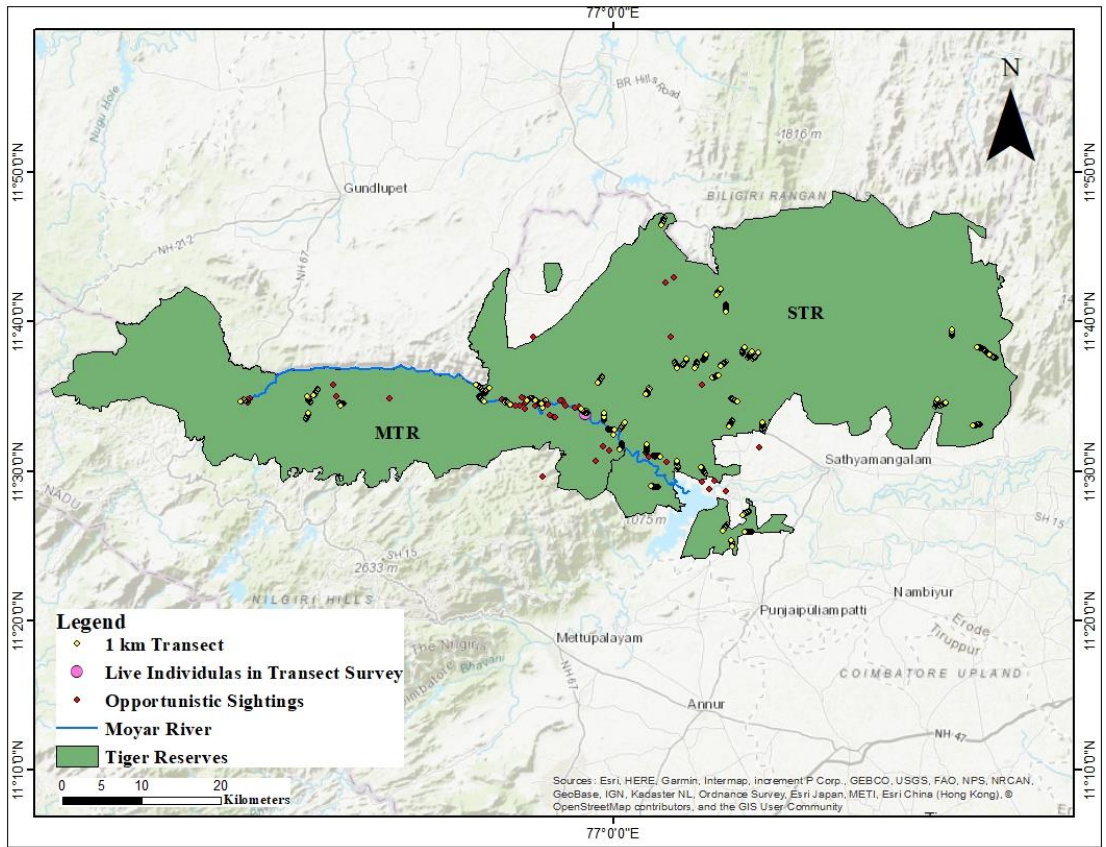


Fig. 3.9. Python detection locations of Sathyamangalam and Mudumalai Tiger Reserves

1. To quantify the microhabitat use of Indian rock pythons

Q. Is there any relationship between male and female microhabitat use?

2. To determine the home range characteristics of Indian rock pythons

Q. What would be the home range size of pythons?

Q. Does body size affect the home ranges of Indian rock pythons?

3. To generate information on homing behaviour of translocated Indian rock pythons

Q. Do release distances have any role in the homing ability of Indian rock pythons?

Q. What would be the maximum distance at which the translocated pythons can return?

4. To document the thermoregulatory behaviour of Indian rock pythons

Q. How do environmental variables and seasonality affect the body temperature in Indian rock pythons?

Vishnu, C.S., Ramesh, C., Talukdar, G., &Thirumurugan, V. (2023). Microhabitat Use of Indian Rock Pythons (*Python molurus*) in the Moyar River Valley, Tropical India. *Indian Journal of Ecology*, 50 (5):1271-1275. <https://doi.org/10.55362/IJE/2023/4046>

4.1. Introduction

Snakes are known to inhabit diverse habitats and microhabitats, which include terrestrial, aquatic, and arboreal. Microhabitats differ from place to place, including stone, burrows, paddy fields, streams, rock, leaf litter, open forests, forest edges, and water bodies (Lalremsanga et al. 2011; Rahman et al. 2014). Among pythons, different species have affinities for various landscapes, habitats, and microhabitats. Indian rock pythons are known to inhabit a wide range of habitats across their distribution range, and also thrive in rocky hills (Hunter et al. 2018; Babar et al 2019). The microhabitat uses in Indian rock python is also diverse. Indian rock python are known to use burrows, tree hollows, marshes, wet rocky ledges along the pools and streams, thickets found in the mangrove, bushes, dense vegetation clumps, large rotten logs, treetops, water reeds, and leaf litters, caves, crevices, and ruins (Sharma 2003; Whitaker and Captain 2004; Mukherjee et al. 2017; Babar et al. 2019). However, the microhabitat usage of Indian rock python in the tropical climate scenario has not been studied yet.

Burmese pythons are the sister species of Indian rock python; in general, they are known from south east Asia, inhabiting forests, lowlands of the tropics, grasslands, agricultural lands, and aquatic habitats (Barker and Barker 2008; Cota 2010; Stuart et al 2012; Rahman et al. 2014). Walters et al. (2016) found Burmese pythons to show a negative selection over freshwater bodies but preferred canopy-associated coniferous forests. However, most of the studies show Burmese pythons to have a

positive selection towards water or aquatic habitats irrespective of the native population or invasiveness in a different geographical area (Cota 2010; Stuart et al. 2010; Rahman et al. 2014; Hunter et al. 2015; Mustascio et al. 2017; Conyers and Roy 2021; Smith et al. 2021). Therefore, habitat selection and use are essential cues for pythons, influenced by various ecological and climatic factors. Indian rock python is a schedule I animal of the Indian Wildlife (Protection) Act 1972. The International Union for Conservation of Nature lists them in the Near Threatened category (Aengals et al. 2021). The species face population decline due to severe habitat loss and poaching (Babar et al. 2019). In this context, understanding the habitat use of this species in the tropical climate will support their conservation management from habitat degradation. Hence this study, quantified the proportion of microhabitat use by Indian rock python in the southern India. The study results would help in identifying and conserving natural microhabitats of the study site, which can also support in identifying suitable translocation sites for rescued individuals from conflict zones.

4.2. Materials and methods

4.2.2. Microhabitat classification

The study was undertaken in the Moyar river valley (Fig. 4.1) area that was classified into eight broad microhabitat types (Fig.4.2): 1. Burrows; 2. Dried fallen trees; 3. Dry bushes (dried bushes dominated by invasive plant *Prosopis juliflora*, debris and sticks, and leaf litter); 4. Green bushes (including *Prosopis* saplings); 5. Trees (including tree hollows and tree roots); 6. Open area; 7. Rocky area (including rocky crevices and beneath the rocks); 8. Water.

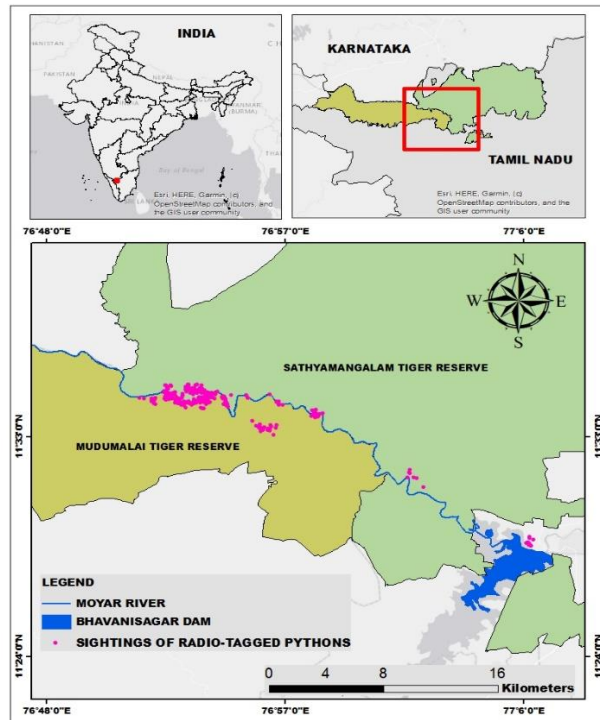


Fig. 4.1. Sightings of radio-tagged pythons in the Moyar river valley



Fig. 4.2. Types of microhabitats
 A. Burrow; B. Dry fallen tree; C. Dry bush; D. Green bush; E. Tree;
 F. Open area; G. Rocky area/ Rocky crevices; H. Water

4.2.3. Surgical method for radio-tagging

The three types of VHF implantable radio-transmitters, AI-2 Holohil of different size 17 g and 28 g, and the ATS ARChive ARC400 tag of 14g was used. The transmitters were implanted into the intraperitoneal cavity of individuals after the isoflurane gaseous anaesthesia (Renurt and Cundall 1984). Simultaneously, morphometry details were collected for each individual. In addition, we confirmed that the mass of each transmitter did not exceed 0.26 % body mass of the individuals. The individuals were given post-surgery care for a week at the veterinary unit of the Sathaymangalam tiger reserve prior to release.

4.2.4. Analysis

The radio-tagged pythons were tracked on different days from 2018 to 2020 and information on microhabitat of each python was noted in the field and calculated the proportion of sightings in each microhabitat. The male and female microhabitat use association was tested by using the chi-square test. Proportion of male and female microhabitat use was calculated using the following formula:

$$\text{Microhabitat use (\%)} = \frac{\text{No. of observations in a particular microhabitat}}{\text{Total observations of males or females}} \times 100$$

4.3. Results

4.3.1. Relationship of pythons with microhabitats

The null hypothesis of the study was that there would be a significant association between the microhabitat use of male and female pythons. However, the null hypothesis was supported by the results, which showed that the microhabitat use of male and female pythons was significantly associated ($\chi^2 = 29.40$, $v=7$, $p < 0.001$) (Table. 4.1 & Table. 4.2). Pythons exhibit a pattern of microhabitat use, showing a high preference for dry and green bushes, irrespective of sex.

Table. 4.1. Frequency of microhabitat use by radio-tracked Indian rock pythons

	Burrows	Dead Fallen Trees	Dry Bushes	Green Bushes	Open Areas	Trees	Rock Crevices	Water	Total
Male	5	15	64	66	18	21	26	2	217
Female	1	8	40	90	11	10	12	12	184
Total	6	23	104	156	29	31	38	14	401
Total %	1.45	5.73	25.93	38.90	7.23	7.73	9.48	3.49	100

Table. 4.2. Observed and expected frequencies (Chi-Square test)

Observed frequencies									
	Burrows	Dead Fallen Trees	Dry Bushes	Green Bushes	Open Areas	Trees	Rock Crevices	Water	Grand Total
Male	5	15	64	66	18	21	26	2	217
Female	1	8	40	90	11	10	12	12	184
Grand Total	6	23	104	156	29	31	38	14	401
Expected frequencies									
	Burrows	Dead Fallen Trees	Dry Bushes	Green Bushes	Open Areas	Trees	Rock Crevices	Water	Grand Total
Male	3.24688	12.4464	56.2793	84.419	15.6933	16.7755611	20.5636	7.57606	217
Female	2.75312	10.5536	47.7207	71.581	13.3067	14.2244389	17.4364	6.42394	184
Grand Total	6	23	104	156	29	31	38	14	401

4.3.2. Proportionality in microhabitat use

According to the study, among the microhabitats, female pythons utilized 49% green bushes, while male pythons used green bushes only 30% (Fig 4.3, 4.4). In contrast, male pythons used green and dry bushes in equal proportions (30%), while female pythons were observed to use dry bushes only 22%. Most pythons were observed in dry bushes and green bushes during the study. Male pythons were seen the least inside water bodies 1%, while females were observed in water 7% of the sightings. Burrows was the least used microhabitat by female pythons (1%), while males were sighted in burrows 2% of the sighting. The study found that male pythons used rocky areas or rock crevices more often than females (12% compared to 6%). Male pythons were sighted in open areas more frequently than females, with a proportion of 10% compared to 5%. On the other hand, male pythons were found in treetops and tree hollows at a proportion of 8%, while female pythons were used this microhabitat 6%. Dead fallen trees were used as microhabitats by males at a ratio of 7%, compared to only 4% by females.

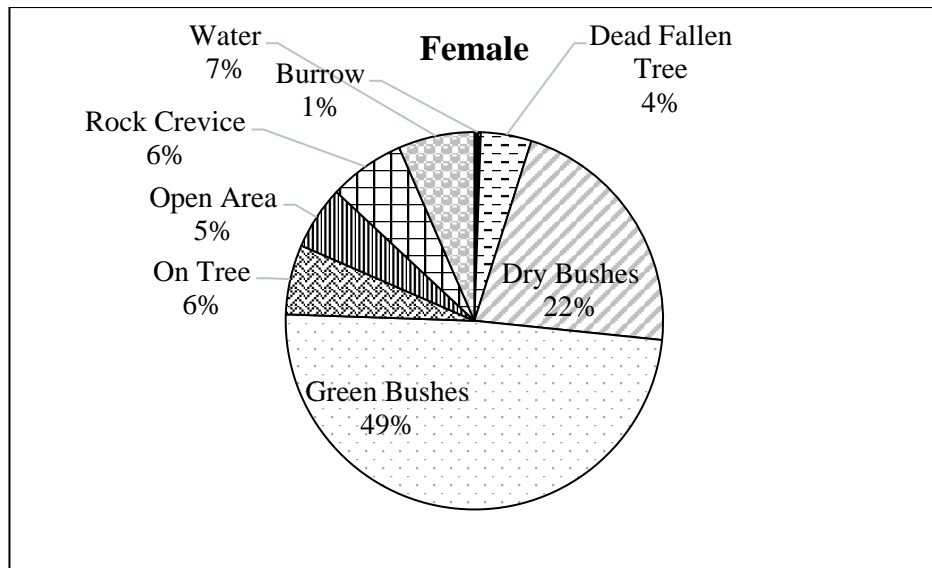


Fig. 4. 3. Proportion of female microhabitats

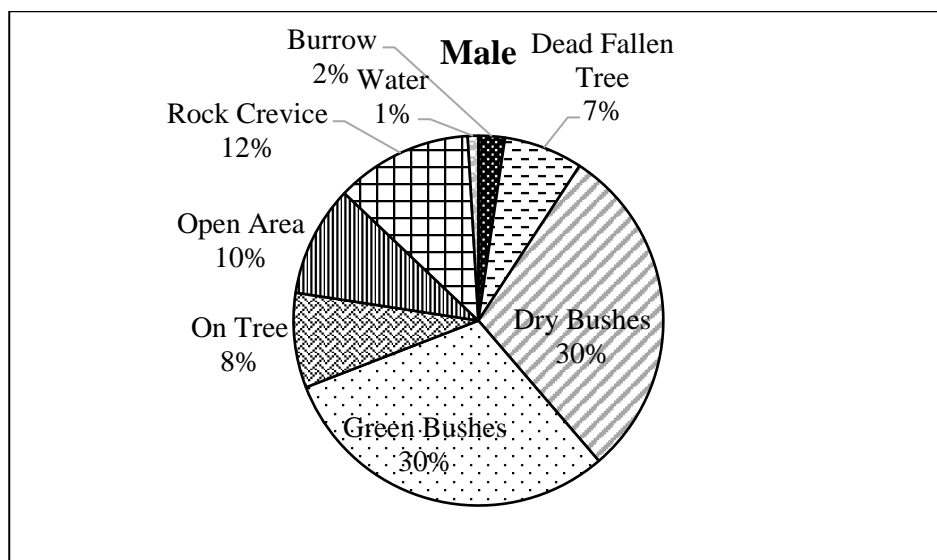


Fig. 4.4. Proportion of male microhabitats

4.4. Discussion

Rocky areas, trees, and dried fallen trees are the other microhabitats used by the Indian rock python in the Moyar River Valley (MRV). The Indian rock python prefer the microhabitats like rock crevices, tree hollows, and rock bottoms during hibernation in northern India between late December and to the middle of February (Sharma 2003). They are also skilled climbers and can suspend

themselves from tree branches, remaining motionless as they wait for prey to come within reach (Sharma 2003). Similarly, open areas can be beneficial for maintaining thermoregulation in pythons. A study on *Hyperolius viridiflavus* found that thermal specialization for hot temperatures was associated with open areas (Lelièvre et al. 2011).

A similar study on Burmese python conducted in Bangladesh reported that the pythons strongly preferred microhabitats such as bushes and thickets. The major habitat type observed was bushy habitat or degraded forest, while the least observed habitats were paddy fields and trees (Rahman et al. 2014). Dry bushes are the hiding sites for pythons, where they are better camouflaged and await prey, in addition to being helpful to avoid predation. The moist substrate along the dry bushes is an essential microhabitat for *Phrynonax poecilonotus* in another tropical country Brazil (Dos Santos-Costa et al. 2015). Studies conducted in the Keoladeo national park have shown that Indian rock python prefer burrows as microhabitats, particularly those located under *Salvadora* bushes (Ramesh 2012). Burrows are engineered shelters that provide crucial refuge and protection against temperature extremes, fire, and predation (Mukherjee et al. 2017, Ramesh and Kamalakannan 2018).

Pythons have a strong affinity for water and prefer to reside in it. Indian rock python, is a good swimmer and can remain submerged in water for at least 30 minutes if necessary (Sharma 2003). Similarly, most studies on Burmese pythons show that this species has a positive selection towards water or aquatic habitats (Barker and Barker 2008, Cota 2010, Stuart et al. 2010, Rahman et al. 2014, Hunter et al. 2015, Mustascio et al. 2017, Conyers and Roy 2021, Smith et al.

2021). These observations suggest that water plays a critical role in the behaviour and biology of pythons.

All the microhabitat types described are crucial for fulfilling the ecological requirements of this species in the study area. However, these microhabitats are often overlooked in many conservation plans. It is essential to consider them in conservation and management practices to ensure the well-being of these species.

4.5. Conclusions and recommendations

This study concludes that there is a significant relationship between sex and microhabitat use in pythons. The proportion of microhabitat use was found to vary according to microhabitat types. Indian rock python in tropical regions, where they tend to prefer bushes, can provide insight into their ecology, as they have been known to prefer burrow microhabitats in sub-tropical regions. Knowledge of the exact microhabitats used by Indian rock python is essential for effective conservation and management in the context of habitat fragmentation and changing climatic conditions. All of the microhabitat types described are crucial for fulfilling the ecological needs of this species in the study area. The significance of microhabitats often being overlooked in many conservation plans, it is critical to be considered. It is a very critical component in conservation and management practices to ensure the well-being of this species. Also, long-term studies on habitat use in pythons will provide more precise results and information on seasonal shifts in their habitat use.

This chapter has been published

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5.1. Introduction

An animal's space use primarily reflects spatial availability of its resources (Waser et al. 1979), whether those resource are shelter, food, mates, or other necessities. Home range quantification is one of the primary components in animal habitat-resource selection studies that can draw behavioural-ecological inference across spatiotemporal scales (Silva et al. 2018). Spatial-habitat requirements and accurate natural history information are essential for developing adaptive conservation and management plans (Hyslop et al. 2014). The foraging patterns, migration and dispersal, and breeding success are all fundamental parameters directly associated with animal space use (Gurarie et al. 2009; Cagnacci et al. 2016). Home range size can correspond with the animal's body size (Seton 1909; Noonan et al. 2020), where larger snakes tend to have larger ranges (Mace et al. 1984).

Like many groups, snakes are facing a widespread decline worldwide (Reading et al. 2010), so collecting information on home range, habitat use, and movement patterns is essential to highlight areas where human-snake confrontation needs to be reduced. Due to human activities, suitable habitat is becoming fragmented or isolated; therefore, species with low dispersal potential are highly vulnerable to local extinction (Parvinen 2004). A thorough understanding of spatial and temporal habitat requirements can aid resource managers in protecting species and the specific landscape features on which they depend (Morris 2003). A critical element

in species conservation is knowledge concerning habitats (Noss 1997; Brito 2003) as well as the movement and activity of animals within suitable habitats (Charland and Gregory 1995; Morales and Moorcroft 2010). In addition, knowledge of specific resources and microhabitats used by species is vital for effective species management (Morrison 2001; Miller and Hobbs 2007).

Radiotelemetry is an essential tool for studying snakes because of its low detectability (Fitch 1987; Dorcas and Wilson 2009); hence with radiotelemetry, we can gain insight on their requirements. The application of radiotelemetry allows for consistent determination of the snake's location, that in turn aids in identifying the habitat preference of snakes, frequency of its movement, distance moved, and home range (Ward et al. 2013).

Like many snakes, the Indian rock python's ecology is only partially understood. Only a few studies on Indian rock python have taken place in India; the first-ever study on the general ecology and population estimation of this species was conducted in Keoladeo National Park, Rajasthan, covering an area of 29 km² (Bhupathy and Vijayan 1989). The Indian rock python is a large, heavy-bodied, ambush predator. Indian rock pythons are non-venomous snakes with an average adult snout-vent length of six to eight metres (Bhupathy 1990). They occupy a diversity of habitats in the Indian- sub-continent, from dry land (semi-arid regions of Rajasthan), to wetland areas and rainforests (Western ghats, Eastern ghats and Coastal regions) (Kamalakannan 2009). They are semi-arboreal and prey upon a variety of small to medium-sized mammals, birds, and lizards (Bhupathy et al. 2014). Python activity is unimodal during winter days and bimodal in spring and summer in semi-arid conditions, active early noon and late afternoons (Bhatt and

Choudhury 1994). Overall Indian rock python populations appear to be decreasing and has been listed as Near Threatened category by International Union for the Conservation of Nature and Natural Resources (IUCN) (Aengals et al. 2021). Also, they mentioned the Appendices I of the CITES. Therefore, it is imperative we work to gain a better understanding of this species requirements.

In this chapter, we studied the home ranges of the Indian rock python and explore how body size may influence home range size.

5.2. Methods

5.2.1. Study site

The Moyar River is flowing between Sathyamangalam and Mudumalai Tiger Reserves; which river contributes water to the Bhavani sagar dam in Tamil Nadu, south India. The area comes under the Nilgiri biosphere reserve-Sigur plateau, which is the connecting point of the Western and the Eastern ghats (Samson et al. 2016), and home to a diversity of wildlife (Gokula and Vijayan 1996; Ramakrishnan and Saravanamuthu 2012). The Mudumalai Tiger Reserve (MTR), is a section of the Western ghats (11°32'– 11°43'N, 76°22'–76°45'E) well-known for its rich floral and faunal diversity covering an area of 588.59 km² (Samson et al. 2016). The major forest types of the reserve are southern tropical dry thorn forest, southern tropical dry deciduous forest, southern tropical moist deciduous forest, southern tropical semi-evergreen forest, moist bamboo brakes, and riparian forests (Champion and Seth 1968). The Sathyamangalam Tiger Reserve (STR), established in 2013 and covering an area of 1400 km² (Sathya and Jayakumar 2017), is at the confluence of Eastern and Western ghats (Vishnu and Ramesh 2021), and is one of the largest tiger reserves of Tamil Nadu (10°29'15" to 11°43'11" N and 76°50'46" to 77°27'22" E). The elevation ranges between 227

meters and 2198 meters above sea level. The study region has three major seasons: monsoon, post-monsoon and summer (Venkitachalam and Senthilnathan 2016). It receives a mean annual rainfall of 850 mm, and the mean minimum and mean maximum temperatures are 21°C and 28°C (Rajput et al. 2019).

5.2.2. Capture, morphometrics, and radio tracking

We located pythons by looking for tracks, shed skins, holes, termite mounds, and dense hedgerows in the forests. Also, we rescued pythons from the human settlements and agriculture areas. We used already tracked individuals to locate new individuals during the mating season. We hand-captured the pythons (Fig.5.1) and temporarily restrained each individual in a snake bag within a large plastic storage container.

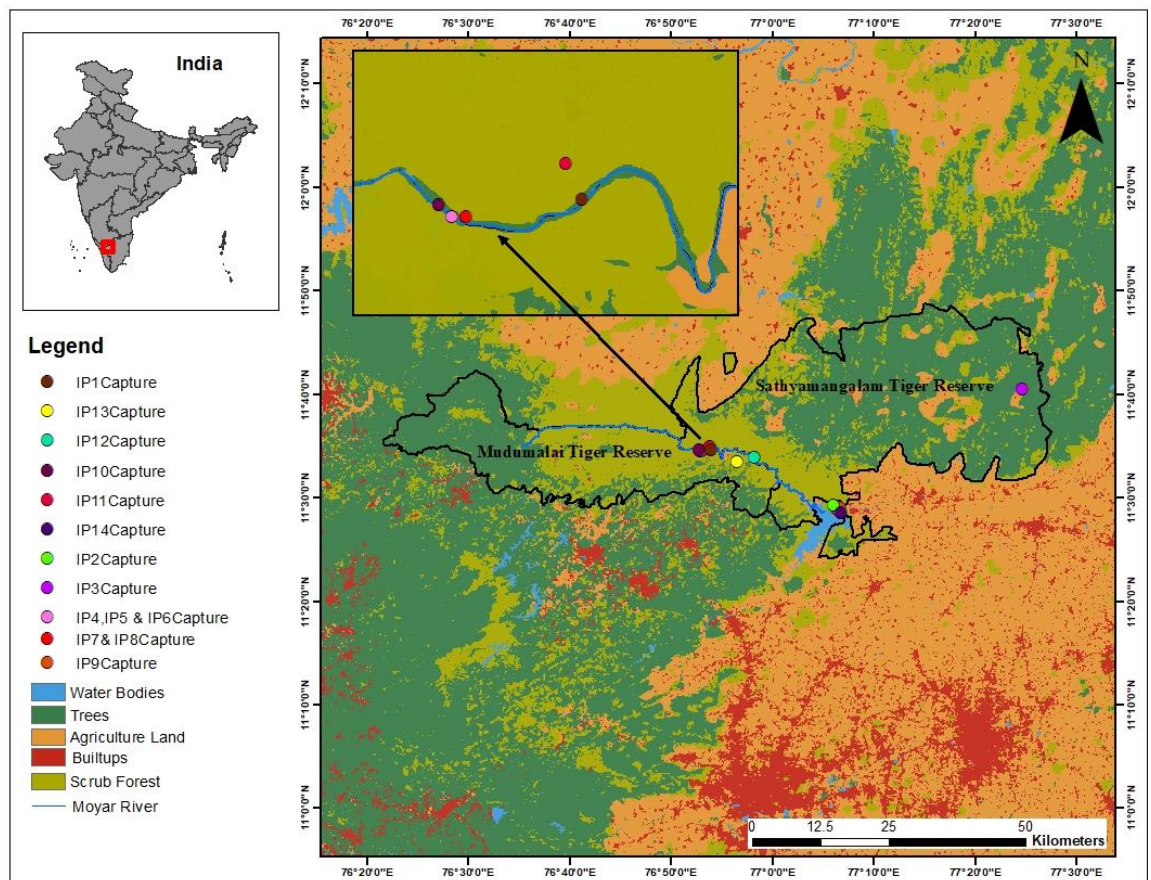


Fig.5.1. Capture locations of pythons in Moyar river valley landscape

Pythons were sedated before the surgery and measured the standard length with a measuring tape (snout-to-vent SVL, in centimetres), and taken mass (kg) in kilograms with a digital weighing balance. Also, each python was identified/marked based on the blotch pattern method (Bhupathy 1990). Following previous literature, python capture and radio transmitter implantation were completed (Ramesh et al. 2019a). Snakes were anaesthetised with isoflurane gaseous anaesthesia during surgeries and implanted with VHF radio-transmitters intraperitoneally (Reinert and Cundall 1982) at the STR veterinary unit. The VHF implantable transmitters were mainly AI-2 Hollohill models, which was of two different sizes, 28 g and 17 g. We also used the smaller ATS ARChive ARC400 transmitter tag model VHF implantable transmitter (14 g). Transmitters did not exceed 0.26% of the snake's body mass.

We conducted radio tracking between 2018 December and 2020 December within STR and MTR. We used 12 pythons captured in conflict areas and the forested areas that were translocated and released, to know the homing instinct. The translocated treatment 0.2 – 55.7 km from capture locations to areas with suitable habitats (evidenced by the presence of pythons). We released two pythons at the location where they were originally captured (control). We recorded GPS locations on each tracking day with the help of a handheld GPS device, Yagi-type antenna, and ATS receiver, and used triangulation to determine the individuals' location. We made efforts to achieve direct sightings using the homing in method.

5.2.3. Home ranges analysis and comparisons

We assessed home ranges using Autocorrelated Kernel Density Estimators (AKDE) (Fleming and Calabrese 2017); using the ctm package through R studio

(Fleming and Calabrese 2021). AKDEs can provide an advantage over traditional home range estimators as it accounts for the autocorrelated nature of animal movement data, as well as mitigating against biases stemming from inconsistent tracking time lags (Calabrese et al. 2016). AKDE's ability to handle inconsistent time lags is beneficial when tracking is conducted using manual radio-telemetry, which is vulnerable to interruptions that inclement weather, staff limitations, and equipment failures can cause. We generated variograms to assess the range residency of the pythons and to determine whether we had adequate data to estimate home range areas. The variograms plotted the average square distance travelled at different time lags (Fig.5.3); we visually examined the variograms and considered those that were not reaching an asymptote as indicative of an unstable range (i.e., the home range estimates are likely to be unreliable). Range residency is a key assumption for AKDE home ranges, as such we only use home range area estimates from individuals closest to showing range residency in further analysis (although low effective sample sizes limit confident inferences). We excluded locations for IP02, IP04, and IP07 that appeared to be homing behaviour post-translocation, so the AKDEs calculated better followed the assumption of range residency. We proceeded to fit a number of different movement models using different movement processes to the data: Ornstein-Uhlenbeck (OU), Ornstein-Uhlenbeck Foraging (OUF), and Independent Identically Distributed (IID). Ornstein-Uhlenbeck models account for the central tendency we would expect from an animal occupying a stable home range; OUF is an expansion on the OU model, additionally accounting for autocorrelation in movement speed. Lastly, IID models assume independence between locations and are the same as traditional kernel density approaches. In addition to the different processes, the range of

models also considered whether the range was best described as isotropic (circular) or anisotropic (elliptical). We fit models using the perturbative hybrid residual maximum likelihood method (pHREML) (Fleming et al. 2019); and selected the best model based on dAICc values of less than two. Where possible, we recovered other characters of the home ranges –home range crossing time and effective sample sizes. However, for some individuals, the low effective sample sizes prohibited crossing time and speed estimations. To estimate the final area estimates to be reported, we opted for a weighted 95% contour and selected the point estimate for further analysis. We selected 95% over other contours as it is the most commonly used in reptile studies (Crane et al. 2021) and adequately avoids extra-range movements (Alston et al. 2022).

We took the 95% contours point estimates from the weighted AKDEs to assess whether the area used by pythons was related to their mass. We formulated a Bayesian regression model, with a Gamma response distribution to examine whether python mass (kg) could predict area usage (km²): $AKDE \sim 1 + Mass$. We did not include any grouping effects such as sex or whether individuals had been translocated because we had insufficient numbers of each with stable home ranges. Therefore, the model was run using eight individuals. We selected a weakly informative prior for the beta coefficient of mass defined by a Cauchy distribution with a location of 0.1, and a scale of 5, to keep the posterior estimation more conservative given the limited sample size (Lemoine 2019). We ran the model over 4 chains, 6000 iterations, with 1000 warmup iterations, and a thinning factor of 10. We assessed model convergence and fit using that values, acf plots, trace plots, posterior predictive check plot, and R² values. We used R v.4.1.1 (R Core Team 2021) via RStudio v.2022 (RStudio Team 2022). We used here v.1.0.1 package

(Müller 2020) to help with relative file path definition. We used `ggplot2` v.3.3.6 for creating figures (Wickham 2016), with the expansions: `cowplot` v.1.1.1 (Wilke 2020), and `scico` v.1.3.0 (Pedersen and Fabio 2021). We used the `dplyr` v.1.0.9 and `stringr` v.1.4.0 packages for data manipulation (Wickham 2019; Wickham et al. 2022). We used `sp` v.1.4.7 (Bivand et al. 2013) for the manipulation of spatial data, and `ctmm` v.0.6.1 (Fleming and Calabrese 2021) to estimate space use. We used `brms` v.2.17.0 (Bürkner 2017; Bürkner 2018; Bürkner 2021) to run Bayesian regression models, with `bayesplot` v.1.9.0 (Gabry et al. 2019; Gabry and Tristan 2022), `performance` v.0.9.1 (Lüdecke et al. 2021), and `tidybayes` v.3.0.2 (Kay 2022) to assess model outputs. We generated R package citations with the aid of `grateful` v.0.0.3 (Rodríguez-Sánchez and Shaurita 2020). The code we used was based upon that used by (Montano et al. 2022).

5.3. Results

5.3.1. Body size and tracking

We tracked 14 individuals, eight males and six females ranging in mass from 3.3 kg to 36.25 kg (mean 10.65 ± 10.75 kg) and snout-to-vent length from 1.72 m to 3.76 m (mean 2.55 ± 0.62 m). Twelve of the pythons were translocated (Table. 5.1). While aiming for a tracking time lag of 24 h, the resulting mean time lag was 16 ± 35 days (range 0.2–238 days; Fig. 5. 2), and the median was five days. The tracking duration ranged from 44 to 695 days with a mean of 444 ± 212 days; during this time, a mean of 29 ± 16 data points collected per individual (range 8–65; Table. 5.2).

Table. 5.1. Characteristics of the tracked pythons. Release range (km), mass (kg), length is SVL + Tail length (cm), SVL = Snout-vent-length (cm), Tail length (cm)

ID	Sex	Resident / Relocated	Release Range	Mass	Length	SVL	Tail length	Name of the Human Settlement (Python Capture)
IP01	Female	Resident	0	32	412	376	36	-
IP02	Male	Relocated	22.5	12.75	280	248	32	Karachikorai
IP03	Female	Relocated	55.7	11.05	350.5	310.3	40.2	Gundri
IP04	Female	Relocated	1.9	36.25	370	342	28	-
IP05	Male	Relocated	3.2	11.35	263	229	34	-
IP06	Male	Relocated	3.3	11.3	272	252	20	-
IP07	Male	Relocated	4.7	5.1	222	194.5	27.5	-
IP08	Male	Relocated	3.13	3.3	198	172	26	-
IP09	Male	Relocated	21.2	10.2	286	251	35	Bhavanisagar Dam

IP10	Male	Relocated	9.93	10.15	268	238	30	-
IP11	Female	Relocated	2.32	6.65	226	197.5	28.5	-
IP12	Female	Relocated	0.2	31.4	384	340	44	-
IP13	Male	Resident	0	12.8	237	211	26	-
IP14	Female	Relocated	10.96	24.8	270	215	55	Factory premise, Karachikorai

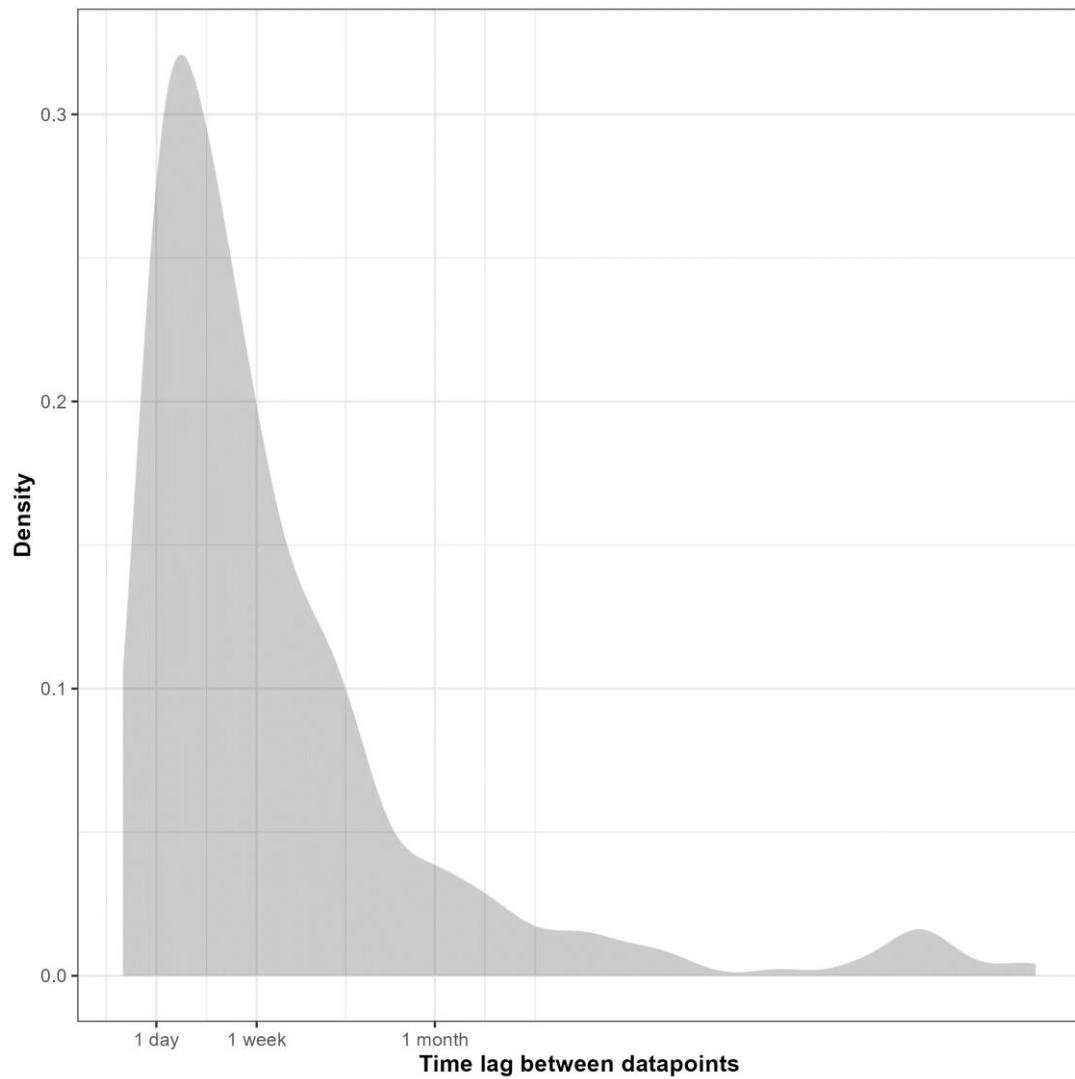


Fig. 5.2. Distribution of the time lags between subsequent data points. Note that the x scale is square-rooted

Table. 5.2. Tracking summary

ID	Start date	End date	Durati on (days)	Mean \pmSD time lag (days)	Number of datapoints	95% AKDE point estimate (km²)	Lower 95% CI of AKDE estimate (km²)	Upper 95% CI of AKDE estimate (km²)	Top fitting movement
IP01	2018-12-16	2020-11-10	695.1	10.9 \pm 29.9	65	1.51	0.97	2.17	OU anisotropic
IP02	2019-01-20	2020-11-10	660.3	17.8 \pm 32.3	38	-	-	-	-
IP03	2019-01-25	2019-03-19	53.2	5.3 \pm 6	11	-	-	-	-
IP04	2019-01-21	2020-09-08	595.9	21.3 \pm 41.6	29	4.48	2.55	6.96	OU anisotropic
IP05	2019-01-21	2020-02-22	397	11.3 \pm 17.2	36	8.07	5.8	10.7	IID anisotropic
IP06	2019-01-07	2020-10-27	659	12 \pm 25.5	56	1.59	1.2	2.03	IID anisotropic
IP07	2019-03-07	2020-03-12	370.9	24.7 \pm 38.8	16	-	-	-	-
IP08	2019-03-08	2020-12-04	637.1	30.3 \pm 49.1	22	6.03	3.08	9.96	Ouf anisotropic

IP09	2019-05-19	2019-07-02	44.1	6.3 ±11.3	8	-	-	-	-
IP10	2019-05-29	2020-10-30	520.2	22.6 ±48.9	24	-	-	-	-
IP11	2019-07-27	2020-11-06	467.9	14.6 ±31.7	33	-	-	-	-
IP12	2019-07-26	2020-11-30	493.1	22.4 ±43.7	23	-	-	-	-
IP13	2019-12-13	2020-11-02	325.1	19.1 ±42.1	18	-	-	-	-
IP14	2019-12-26	2020-10-12	290.8	13.8 ±51.4	22	-	-	-	-

5.3.2. Home ranges analysis and comparisons

Our initial examinations of the variograms suggested questionable range stability; therefore, interpretation of needed to be done with caution (Fig. 5.3). The tracking data of some individuals yielded extremely low effective sample sizes, undermining our confidence in any resulting estimates of area (IP10, 11, and 12). Overall, python tracking data yielded a mean effective sample size of 13.0 ± 17.2 (0.02–56.0). When limited to individuals with effective sample sizes over ten, the mean effective sample size was 29.6 ± 18.7 (range 11.6–56.0). From the potentially more-stable individuals, we were able to retrieve three estimates of home range crossing time, with a mean of 6.0 ± 3.9 days (range 2.7–10.3 days).

We estimated the weighted AKDE home ranges for all individuals but only used those with effective sample sizes above 10 for further analysis. The 95% contour point estimates had a mean of 3.7 ± 1.4 km² (range 1.36–8.1 km², n=5; Fig. 5.5). But this hides some of the variations; the lowest area estimate (lower 95% confidence interval) was 0.8 ha, and highest was 10.7 km². Using ctmm's meta function (that takes into account uncertainty) on the top fitting models, the population mean was 4.2 km² (95% CI. 1.7–8.5 km², n=5; Fig. 5.4). Although the sample size prohibits robust statistical comparisons, females appear to have smaller ranges 1.6 km² (95% CI. 1.2–2.2 km², n=2) compared to males 5.0 km² (95% CI. 4.1–6.0 km², n=3). Of the stable individuals, only one was resident (IP01) and had a range of 1.7 km² (95% CI. 1.1–2.4 km²). The translocated individuals had a larger mean range of 4.8 km² (95% CI. 1.7–10.9 km², n=4).

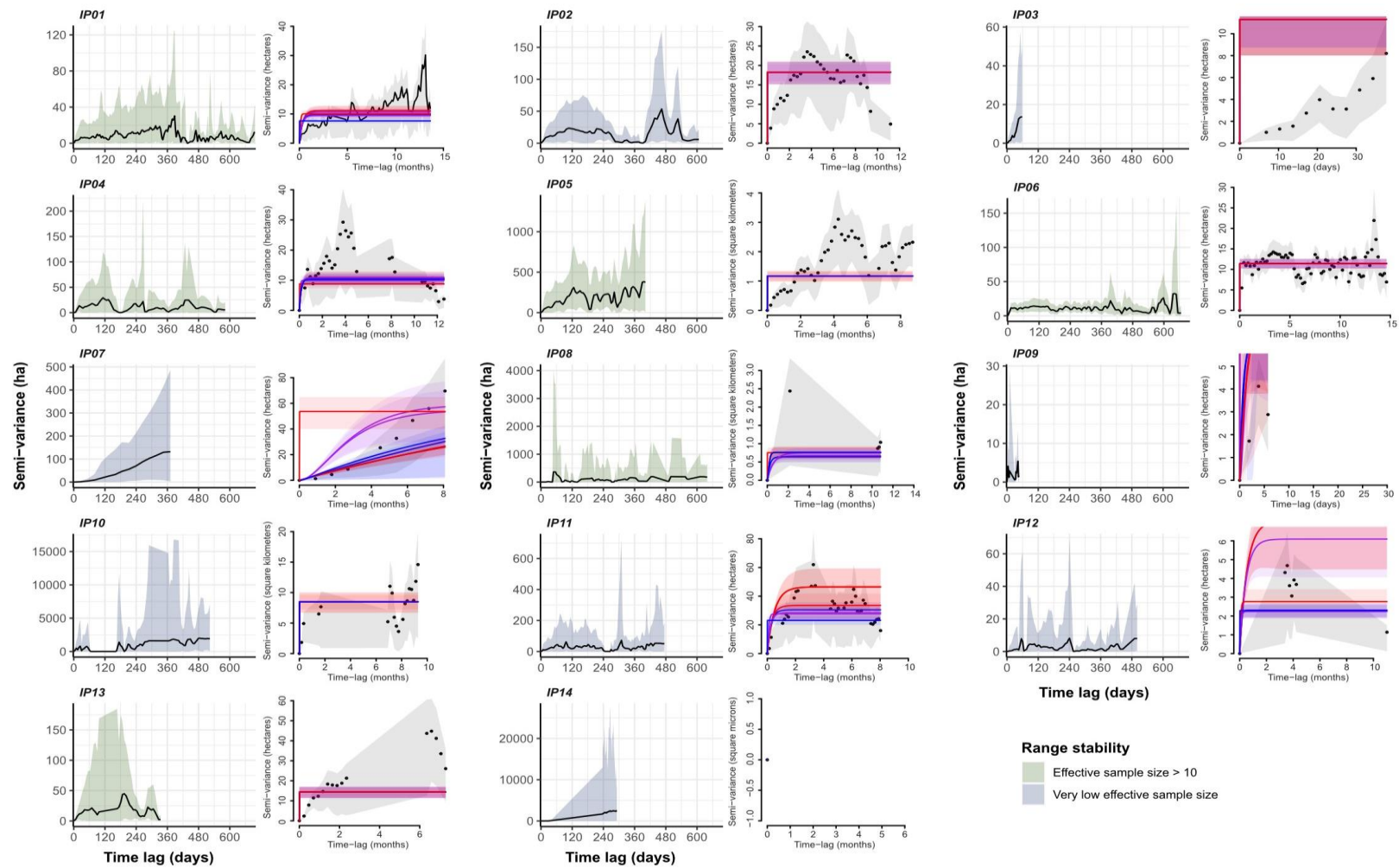


Fig.5.3. Variograms generated for all individuals with highlighting to show those with sufficient effective sample sizes to be included in further analysis.

Right-hand plots contain zoomed views to show the movement model fits.

IP01 and IP04's movements were best described by an OU anisotropic model suggesting the presence of central tendency (although IP04's dAIC was within 2 of the Ouf model). IP08 also supports this, but the Ouf anisotropic performs best, showing that IP08's data also contains autocorrelated velocities (although IP08's dAIC was within 2 of the OU model). IP06's movements were best described using the IID anisotropic model, suggesting that location data could be modelled independently. The anisotropic or elliptical nature of the home ranges is visible in Fig.5.5.

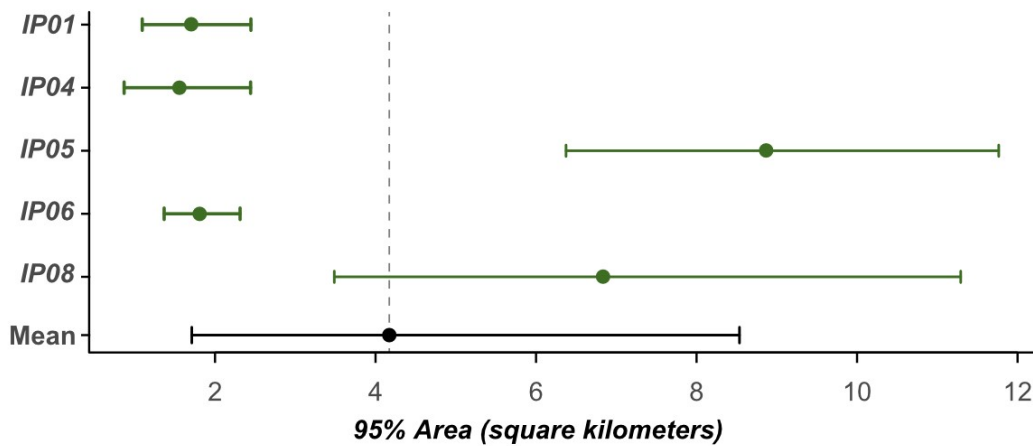


Fig. 5.4. The estimated home range sizes of Indian rock pythons, alongside the mean home range size. All estimates are paired with 95% confidence intervals.

Our Bayesian regression model successfully converged, confirmed by those values~1 and diagnostic plots (that can be found at: <https://osf.io/d58rs/>). The resulting model suggested a negligible positive correlation between 95% home range area and mass ($\beta=0.02$, 95% CI 0.00–0.05; Fig. 5.6.). However, the estimate was very uncertain. The posterior predictive check plot revealed that predicted draws did not fit particularly well with the original data. The R^2 value of 0.36 was paired with very wide credible intervals (95% CrI 1.23e-07, 0.58).

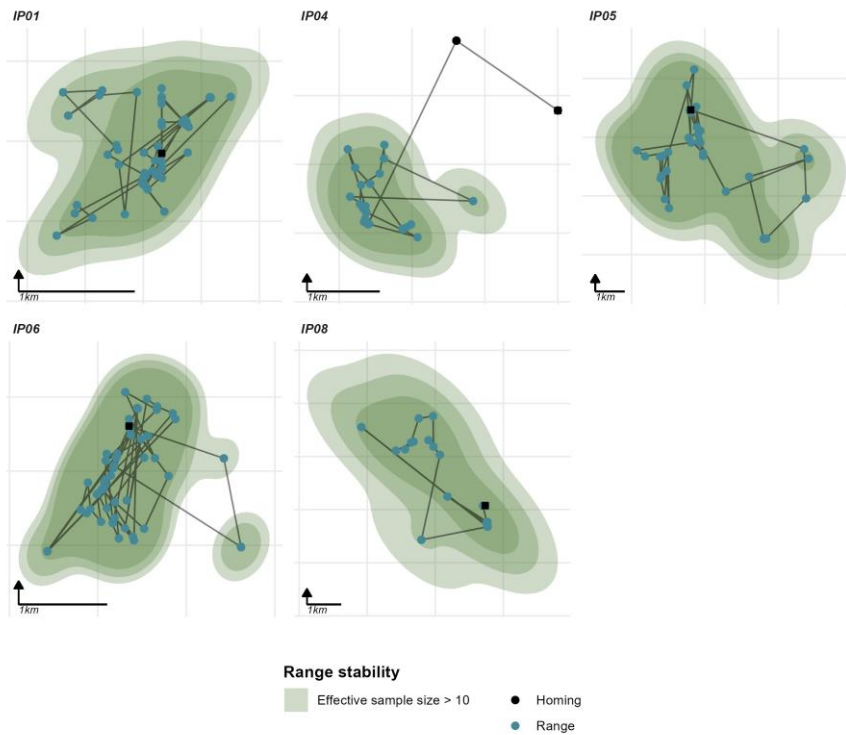


Fig. 5.5. The range of resident individuals AKDE areas mapped. Square points indicate the release site of the individual. Differing opacity levels show the 95% confidence intervals surrounding the 95% contour estimate. Note all individuals are all on independent scales.

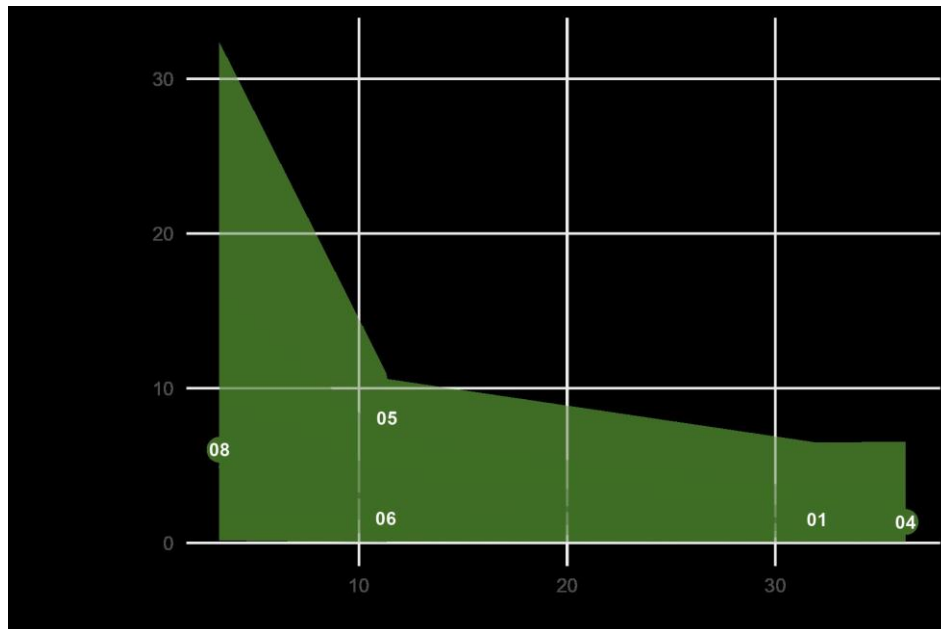


Fig. 5.6. Predicted draws from the 95% contour area point estimate~mass model, illustrated with original data points (with python IDs) and 95, 80, and 50% credible intervals.

5.4. Discussion

In our study, the Indian rock python from the Moyar valley, southern India, occupied an average home range of 3.7 km² (AKDE 95%-point estimate) or 4.2 km² using ctm meta-analysis functionality. While inconsistencies in the manual tracking affected the home range estimation for all the individuals, five individuals provided highly effective sample sizes to begin to gauge home range size (Fig. 5.5).

Homing has impacted home range estimates in a few individuals. Even though IP02, IP04, and IP07 had stable ranges, we excluded their home range estimations due to their homing behaviour after translocation. If we included these individuals in the home range estimation, the AKDEs would estimate the entire range after translocation as their resident ranges. We have reduced the biases by excluding them from the home range estimation.

The five individual range estimates come with broad confidence intervals highlighting the uncertainty surrounding our estimates, with the point estimates alone ranging by orders of magnitude. The largest range (with an effective sample size >10) was from IP7, a translocated male, who ranged approximately 21.7 km². The only resident python with a more stable range appeared to have one of the smaller home ranges at 1.5 km²; however, translocated individuals could exhibit smaller ranges (e.g., IP02 & IP04 covering ranges of ~1.4 km²). While our estimates offer insight into rock python home range size, a larger sample with longer tracking periods would help reduce the uncertainty, and tracking pythons in different sites will help build a broader picture of their movements.

We did not see any clear evidence that larger individuals had comparatively larger home ranges (although the model fit was poor). This contrasts with clearer differences in other similarly sized species. For example, larger King Cobras (*Ophiophagus hannah*) in Northeast Thailand had larger home ranges (calculated using Kernel density estimators) (Marshall et al. 2019), suggesting a potential connection between size, metabolic demands, and foraging effort. These differences may be linked to foraging mode. Large-bodied pythons prefer large prey items like ungulates, as ambush-foraging snakes have comparatively larger prey sizes than active-foraging species; this can curtail their movements due to the time required to digest heavy meals (Glaudas et al. 2019).

While we could not test the differences statistically (due to low sample size and imbalance in the translocation history of individuals), females (IP01 resident and IP04 translocated) appeared to have smaller ranges. This contrasts with other snakes, such as White-lipped Pit Vipers (*Trimeresurus albolabris*); the frequency of movements and distances moved by female snakes are significantly higher than the males in Southern China (Devan-Song et al. 2016).

However, in a study on other large snakes, Eastern Indigo Snakes (*Drymarchon couperi*); female home ranges were 0.76 km², while male home ranges averaged 2.02 km², estimated using Kernel density estimates, respectively (Breininger et al. 2011). It is suggested that larger male ranges are likely a result of mate-searching behaviour (Jellen et al. 2007). In Diamond pythons, *Morelia spilota spilota* males moved long distances, often daily, compared to females (Slip and Shine 1988). Such increased movement during a portion of the year (the mating season) could be the driver behind the larger overall ranges. The potential absence in our study may

be linked to the translocation disrupting usual searches. High female movements tend to be connected to oviposition (Madsen 1984).

Studies on the space use of a sister species Burmese python have been done in different regions: native (Asia) and introduced ranges (North America). The (Minimum Convex Polygon) home ranges of invasive Burmese pythons were reported to average 22.5 km² (Hart et al. 2015), whereas in their native range (Goodyear 1994), the average home range is 0.12 km² (although only over 24 days). A longer duration study on native Burmese python's movements indicates that Goodyear's estimates (Goodyear 1994) are likely underestimates of native Burmese python space requirements. The study (Smith et al. 2021) did not calculate home ranges, instead reporting dynamic Brownian Bridge Movement Model 99% confidence areas that approximately average 0.99 km². As dynamic Brownian Bridge Movement Models aim to quantify uncertainty surrounding a movement path rather than a home range (Roth and Greene 2006), we can expect the range to be larger than 0.99 km². It would appear that the Indian rock python's home range is likely to be considerably larger than the Burmese python (although more robust comparisons would require recalculation of ranges using AKDEs). Previous studies on snakes, including pythons, have shown that the habitat use and their movements can differ in relation to many factors such as body size (Moore and Gillingham 2006; Pizzatto et al. 2009), sex (Moore and Gillingham 2006; Kapfer et al. 2008), season (Diffendorfer et al. 2005; Moore and Gillingham 2006; Bell et al. 2007; Sperry and Taylor 2008; Wisler et al. 2008), and prey availability (Madsen and Shine 1996). Studies focusing particularly on large constrictors have observed the shift of habitat uses seasonally (Shine and Fitzgerald 1996; Slip and Shine 1988; Heard et al. 2004), movement in response to weather changes, and

home range size differing between native and translocated individuals (Brown et al. 2005; Pittman et al. 2014). Failure to track snakes long enough to capture seasonal variation may explain inconsistencies in range estimates and relationships between home range and individual constrictor characteristics.

VHF telemetry remains the primary option for determining snake home range study because of the snake's restrictive body plan. The human or aircraft resources required for VHF tracking increase rapidly with tracking frequency, making data collection expensive and infeasible for high-frequency sampling schedules (Girard et al. 2006). Our study was limited to diurnal hours because of the tiger reserve rules. Various obstacles affected the tracking of pythons, such as the small workforce, limited funding, and an inaccessible landscape with high densities of wild hazards, especially elephants and thorny bushes of *Prosopis* and *Carissa*. The COVID-19 pandemic compounded the difficulties with data collection. This study's resulting low tracking frequency may miss small-scale movements and potentially impact the estimation of home ranges (Girard et al. 2002). Therefore, we have emphasised the findings from individuals with an effective sample size of over 10 using an analysis method that helps to mitigate the biases of low, inconsistent tracking data (Fleming et al. 2018). Fortunately, wide time intervals between location data collection may be less of a concern for large, slow-moving animals (Fisher et al. 2020). This may apply in the case of pythons as they are slow-moving animals' incapable of exceeding 1.6 kph (Szalay 2021) and with a predominantly ambush-focused foraging style.

To conclude, our home range estimate provides baseline information on the Indian rock python, a key early step in exploring what influences the Indian rock python

movement and space requirements. The highest home ranges observed in other species of python: Carpet pythons (*Morelia spilota*) had home ranges from 0.18 km² (Shine and Fitzgerald 1996) to 0.23 km² (Pearson et al. 2005), and Diamond Pythons (*Morelia spilota spilota*) had home ranges of 0.27 km² for females and 0.52 km² for males (Slip and Shine 1988), would initially suggest Indian rock pythons require larger areas. But again, confidence in any comparisons must be tempered as the home range estimation method differs between the studies and the predominance of translocation individuals in our study. Further work is required to identify the drivers behind home range size and initial investigations into how pythons select home range areas to further improve these findings' relevance to conservation planning.

5.5. Conclusion

The study found that the average home range size of Indian rock python is 4.2 km². Knowledge of their home range can inform land-use planning and management decisions for species that overlap with human activities, such as agricultural or urban areas. Managers can reduce negative interactions and promote coexistence by identifying areas of potential conflict and implementing appropriate measures, such as wildlife corridors and buffer zones. When translocating or reintroducing these pythons, home range estimates help determine suitable release sites and ensure that the new habitat provides sufficient resources and space for the species. This information increases the success rate of translocation and reintroduction efforts, enhancing the chances of population establishment and persistence. Aspects of conservation of python provided in details as Annexure -I.

This chapter has been accepted for publication

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6.1. Introduction

The homing capacity of an animal is often quantified using translocation experiments that measure the ability of animals released in an unfamiliar location to orient back home where it was captured (Pitman et.al. 2014). This process has not been studied extensively in snakes (Pitman et.al. 2014). The practice of moving animals for conservation or wildlife management purposes is increasing (Seddon et al. 2007). Animals may be removed from an area due to serious threats to their survival (Tuberville et al. 2005; Griffiths and Pavajeau 2008), conflict mitigation (Sullivan et al. 2004; Bradley et al. 2005), to aid colonization in response to climate change (McLachlan et al. 2007), to increase genetic variation (Madsen et al. 1999), and for the re-establishment of extirpated populations (Pedrono and Sarovy 2000; Moorhouse et al. 2009). Many of these translocation efforts are generally part of larger conservation and the re-establishment of animal populations. However, moving snakes from their capture location appears to be only a short-term solution in situations where animals are capable of navigating home (Clemann et al. 2004; Pittman et al. 2014).

Translocating snakes is a common practice for managing human–snake conflict and is used for the conservation and management of wildlife (Griffith et al. 1989; Butler et al. 2005). However, translocation efforts are sometimes not successful because of the navigational capacity of the species. Pittman et al. (2014) reported that invasive Burmese pythons translocated distances of 21-36 km in South Florida could return home (Pittman et al. 2014). Other studies have reported successful

translocations in which snakes did not navigate home (Dodd and Seigel 1991; Plummer and Mills 2000). A study on the white-lipped pit vipers in China showed snakes translocated greater than 3km were not able to navigate home; however, snakes displayed unidirectional movement not associated with the establishment of a new home range (Devan-Song et al. 2016).

The reintroduction attempts often fail to result in the establishment of viable populations for numerous reasons (Dodd and Seigel 1991; Fischer and Lindenmayer 2000). Translocations cause unintended consequences to the animal, including behavioural changes, reproductive dysfunctions (Reinert 1991), predator naivety (Moseby et al. 2015), and the inability to locate suitable food or shelter (Reinert and Rupert 1999). The low success of reintroduction programs has led to the advancement of many novel techniques that seek to improve the survival and reproduction of translocated individual (Fischer and Lindenmayer 2000; Armstrong 2008; Kingsbury and Attum 2009).

Indian rock pythons are facing severe threats from anthropogenic activities, habitat degradation, and habitat loss, and are currently listed as Near Threatened by the IUCN (Aengals et al. 2021). Further, this species is protected under the Schedule-I of the Indian Wildlife (Protection) Act – 1972 amended 2023 and is listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora. Therefore, minimising human-wildlife conflict while maximizing the survival of this species is the central goal of conservation efforts. In India little is known about the movement behaviour and navigational capacity of Indian rock pythons. The average AKDE (Auto correlated Kernel Density Estimates) home range size of Indian rock python has been reported as 4.2 km², and

the Indian rock python home ranges are known to have larger home ranges than other pythons reported so far (Vishnu et al. 2023).

Previous research on the closely related Burmese python in both its invasive and native ranges have suggested that the Indian rock python may be capable of long-distance movement. The home range size of the Burmese python in the native range was reported to be 12.3 ha over 24 days (Goodyear 1994). Similarly, a study conducted by Smith et al. (2021) reported that Burmese pythons' movement was 41.56 ± 7.43 m per day in its native range.

To understand the homing capacity of native Indian rock pythons, we used radiotelemetry to study the movements and activity patterns of pythons in Moyar river valley, southern India between 2018 and 2020. As part of that study, we radio-tracked 14 individuals of which 11 of those individuals were translocated 200m -50km from their original capture locations (Fig.6.1). Herein, we report and discuss the implications of the movement and homing capabilities of these translocated pythons.

6.2. Methods

6.2.1. Experimental setup and study design

Pythons were located by looking for tracks and shed skins within holes, termite mounds, and dense hedge rows in proximity to human settlement. We also located pythons rescued from human-modified habitats by following radio-telemetered snakes during the mating season. We hand-captured the pythons and temporarily restrained each individual in a snake bag kept within a large plastic storage container. Three pythons (IP2, IP3, and IP9) were captured from human habitation on agricultural land and one python (IP14) was spotted near a factory premise in a habitat patch that connects to forested land. All other individuals were captured

from the core forests to test their homing ability with respect to the translocation distance. We weighed each python and measured snout-to-vent length (SVL), total length (TL), and girth. We additionally took photographs of each python in order to identify each individual using the blotch pattern method (Bhupathy 1990). Python capture and radio transmitter implantation followed Ramesh et. al. (2019). Snakes were anaesthetised during implantation surgeries and implanted with AI-2 transmitters (17g, 24 months, 38 x 15 and 28g, 36 months, 46 x 17) and ATS ARChive ARC400 Transmitters (Tag 32x20x15, 14gms, 239 days) VHF radio-transmitters intraperitoneal (Reinert and Cundall 1982; Weatherhead and Anderka 1984; Vishnu et al. 2023) at the STR veterinary unit. Snakes were released within one week of the original capture. The release locations have been planned with Google Earth software, and trail field surveys were conducted at release locations to check the availability of water, less human interference, prey availability (direct and scats), micro-habitats (rock crevice, bushes, leaf litters, and basking area availability).

We carried out radio-tracking between 2018 December and 2020 December within the Sathyamangalam and Mudumalai tiger reserves at varying intervals. Radio tracking ceased between 17 March 2020 and 06 September 2020 due to COVID-19 pandemic. Eleven of the 14 pythons were translocated 0.2-55.7 km from their capture locations. In comparison, two pythons were not translocated, and IP12 was an individual that was translocated 200 meters away from the capture location. However, since this new location falls within the home range of this individual, we consider it as a resident for the purpose of analysis. Six were translocated short distances (<5km from capture), two were translocated medium distances (9-11km from capture location), and three were translocated long distances (21 – 55.7km

from capture location; Fig. 6.2, 6.3). All pythons were released in a habitat suitable for python (determined by the presence of other pythons in the area). We recorded GPS locations on each tracking day with the help of a handheld GPS device, Yagi-type antenna, and ATS receiver (Vishnu et al. 2023).

We calculated the linear distance between each successive relocation and between each successive relocation and the original capture location. We calculated the mean daily movement for translocated and resident pythons within 60 days of release or until the python moved to within 1000m of the capture location (whichever occurred first). Daily movement was calculated by dividing the straight-line distance between successive relocations by the number of days between relocations. Within the first 60 days post-release, pythons were tracked on average once per week, and sometimes more or less frequently. The frequency of python tracking is detailed in Table 5.2. To determine whether translocated snakes moved more than resident snakes, we used a boxplot to compare max net distance moved between resident and translocated snakes within 60 days post-release. We determined that a python had successfully ‘homed’ if the python moved at least 60% of the translocation distance back to the original capture location.

6. 3. Results

6.3.1. Initial movement behaviour

The mean daily movements of resident snakes within the first 60 days of release were 57.0 m (SD = 49.2 m, N = 3). Mean daily movements of translocated snakes was 208 m (SD = 198 m, N = 11). Translocated snakes moved significantly greater net distances from release than resident snakes within the first 60 days of post-release (Fig. 6.4).

Table 6.1. Radiotelemetry information on resident and translocated snakes. Snakes are organized in ascending order of translocation distance. Note that the snakes translocated greater than 11km failed to navigate in the direction of home. All other translocated snakes moved within the direction of home. *Closest distance to home was not calculated for these snakes because radiotelemetry was interrupted by the covid19 pandemic during the first 60 days post release.

ID	Sex	Translocation Distance (m)	Total Tracking Period (days)	Closest Distance to Home w/in 2 months (m)	Closest Distance to Home w/in 2 years (m)	Days to Closest Distance	Proportion of Translocation Distance Returned
IP1	F	0	695				
IP13	F	0	325				
IP12	F	285	493				
IP4	F	1925	592	214	111	157	0.9423
IP11	F	2323	469	1797	86	96	0.963
IP8	M	3128	638	NA*	1021	565	0.6736
IP5	M	3242	397	427	278	95	0.9143
IP6	M	3290	645	1294	1294	32	0.6067
IP7	M	4670	371	657	353	97	0.9244
IP10	M	9931	530	NA*	1078	491	0.8915
IP14	F	10957	291	NA*	1001	289	0.9086
IP9	M	21232	44	20120	20120	44	0.0524
IP2	M	22459	671	22440	22440	20	0.0008
IP3	F	55680	58	55487	55487	15	0.0035

6.3.2. Evidence of homing

All short and medium distance translocated pythons returned at least 60% of the way to their original capture location (N = 8) (Table. 5.1). Four of these were observed within 400m of their original capture location. All eight snakes moved in the direction of their original capture location, and all moved consistently toward their original capture location for the duration of the study (i.e. none were observed to have travelled greater than 20m farther from their original capture location than the net translocation distance). None of the three pythons translocated long distances moved greater than 5% of the way to their original capture locations.

6.3.3. Long term movement

The three snakes translocated long distances (and did not home) displayed mean daily movements (233 m, N = 3) more similar to short, and medium-distance translocated snakes (199 m, N = 8) and more than resident snakes (57 m, N = 3) (Table. 6.1). This result may indicate aberrant or at least increased movement post-release even for snakes that did not successfully home. However, one long-distance translocated snake radio-tracked for 671 days was observed to have mated 33 days post-release, likely indicating a return to typical movement behaviour.

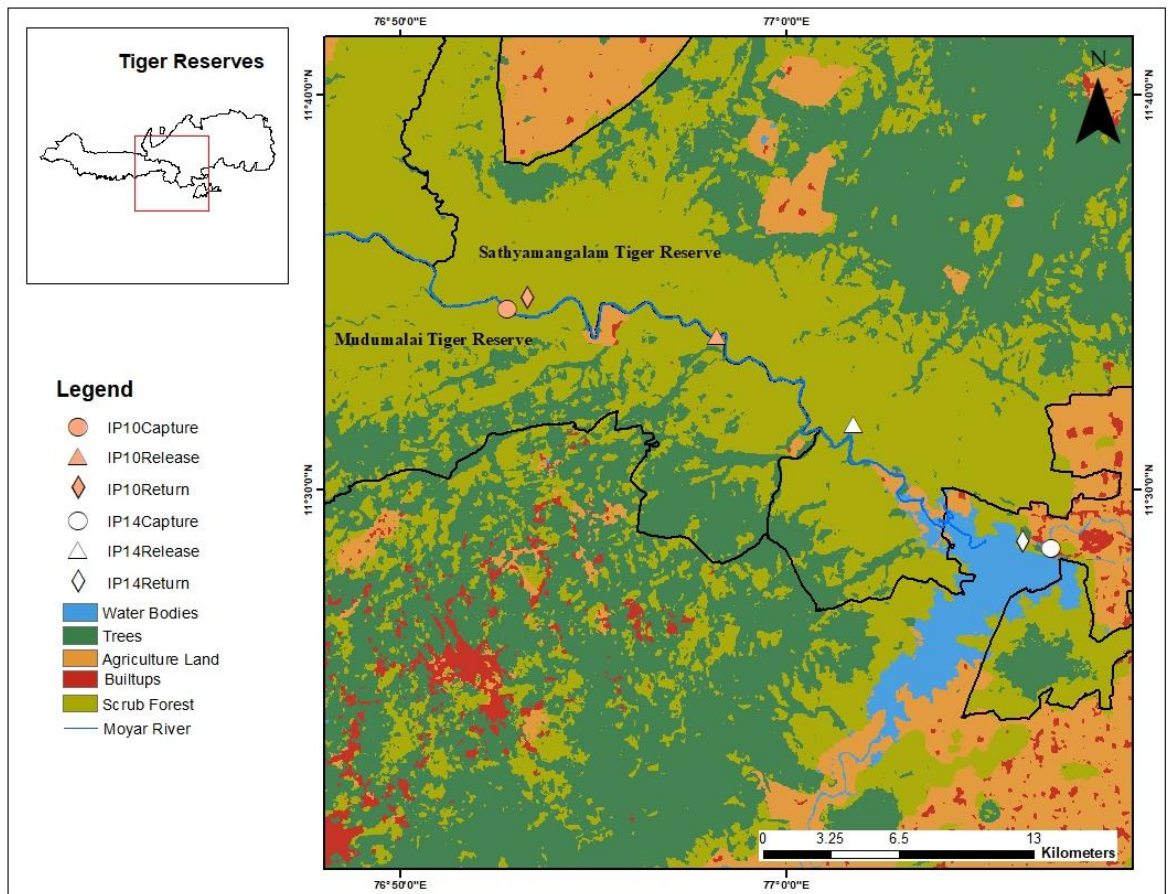


Fig. 6.1. Capture, release, and return location of medium-distance released pythons (9-11 km)

6.4. Discussion

Translocation is considered a controversial conservation strategy because it can result in increased mortality and aberrant movement patterns of translocated individuals in comparison with resident individuals (Shine and Koenig 2001; Butler et al. 2005; Devan-Song et al. 2016). It can also lead to translocation of the problem to another area. Translocation may negatively affect long-lived species with sophisticated navigational capacity or those that depend on local landmarks to navigate. However, long-distance translocation has been used successfully when accompanied by strategies to ensure availability of appropriate habitat for the translocated organisms and the timing of translocation does not negatively impact the phenology of the species (Tuberville et al. 2005). This study suggests that long-

distance translocation may be helpful for the conservation of the Indian rock pythons as long as individuals are translocated to high-quality habitat. All three snakes that were translocated between 25km and 56km from their capture locations did not show homing instinct and were not frequently tracked (see Table 5.5). None were observed to have displayed aberrant movement patterns. For example, IP2M was observed to have mated in the new release location. Longer distance releases into high quality habitat may increase the likelihood of pythons establishing new home ranges in the new environment.

One hundred percent of pythons translocated short distances (<11km) successfully navigated at least 60% of the distance to their original capture locations. These pythons navigated back to their capture locations without the memory of an outward path, these snakes displayed a map and compass sense, most likely using local cues at the release site to determine their position relative to home. The pythons that were translocated to short distances, may have also used local olfactory cues or other locally observed landmarks to navigate home. These results suggest that short-distance translocations will likely generate high homing rates and, therefore, may not significantly reduce human-wildlife conflict over the long term or resolve the purpose for which the snake was translocated.

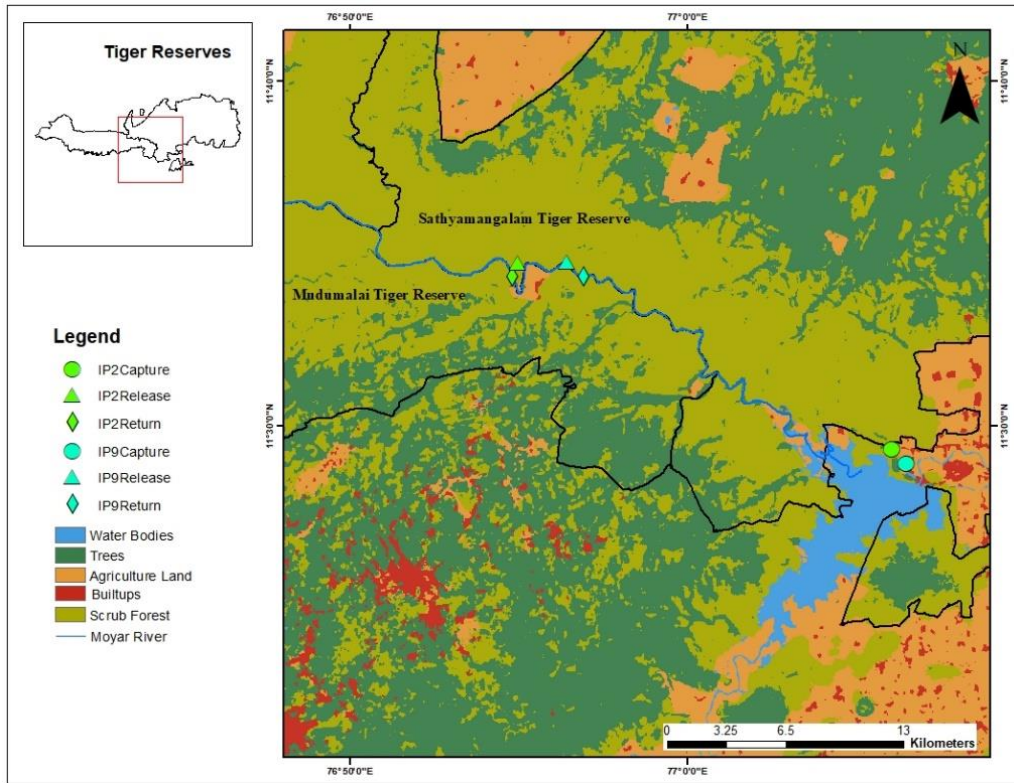


Fig. 6.2. Long- distance translocations of pythons (21-22.4 km)

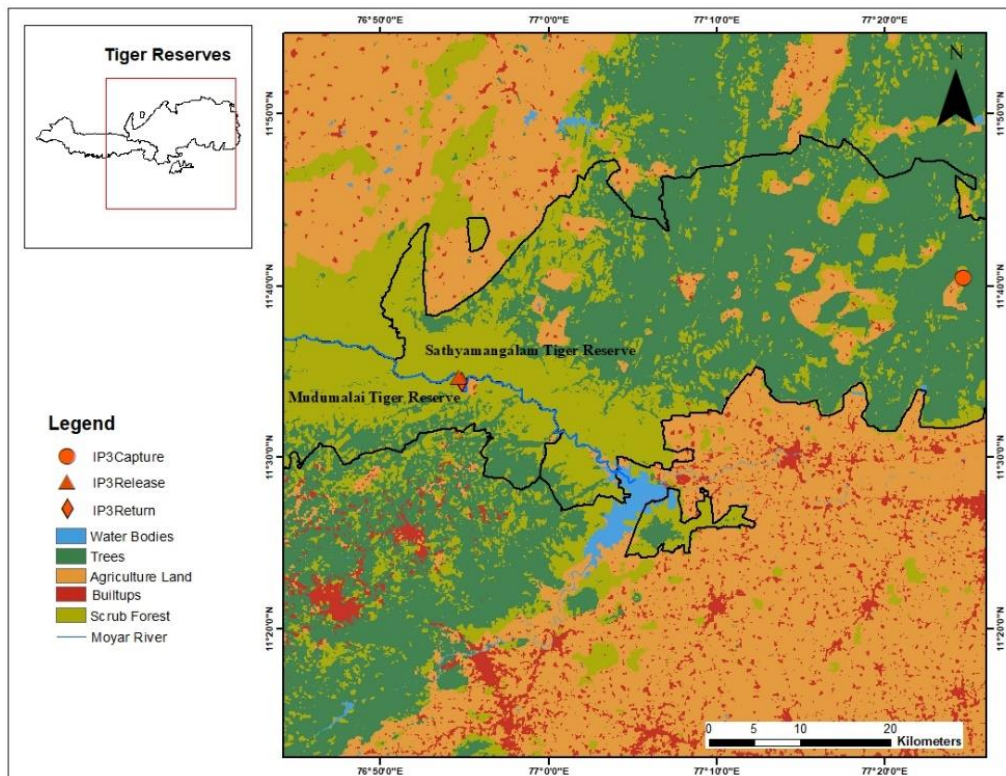


Fig. 6.3. The longest python translocation IP3 (55.7 km)

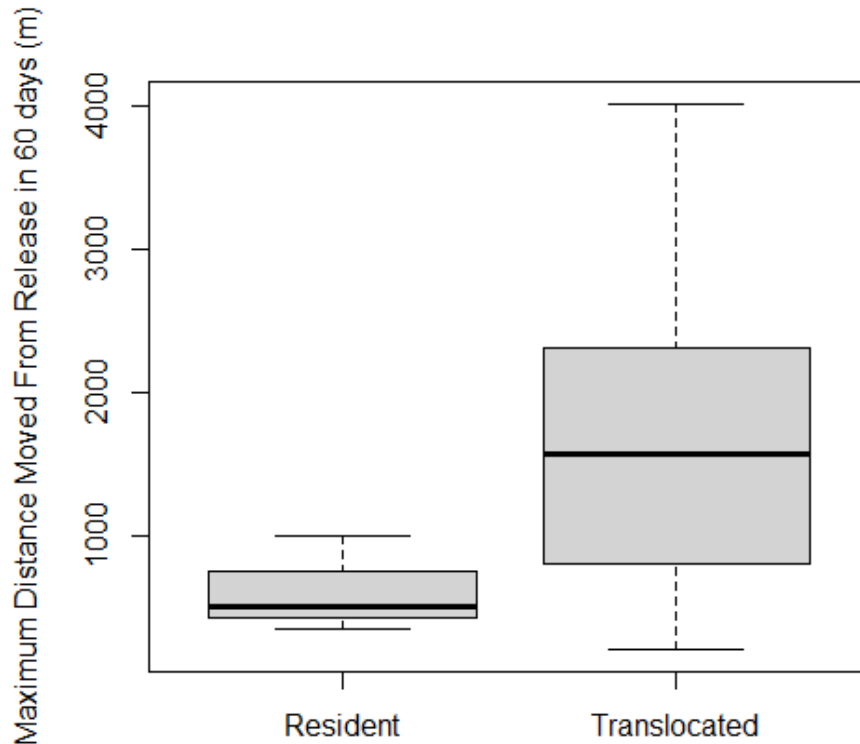


Fig. 6.4. Post-release movement by resident and translocated pythons within 60 days

6.5. Conclusion

The study results indicate that native Indian rock pythons are capable of homing over distances as great as 11km, but we did not find evidence that Indian rock pythons were capable of or motivated to home distances as great as those observed in invasive Burmese pythons in south Florida (Pittmann 2014). The experiment suggests longer distance translocations of Indian rock pythons could disrupt the cues used by snakes navigating shorter distances and thus prevent successful homing. Aspects of conservation of python are provided detail in Annexure -I.

7.1. Introduction

Conduction and convection of heat and radiation are the main factors that tend to raise or lower the temperature of the animal's body. In contrast, chemical transformations raise it, and water evaporation tends to lower it (Gunn 1942). Reptiles are ectothermic and are immensely sensitive to the thermal features of the environment (Carranza et al. 2018). Minute changes in environmental temperatures impact their daily activities, biology, and survival (Wilms et al. 2011; Ribeiro et al. 2012). Similarly, seasonal factors, inter-sexual differences, trophic interactions, and local environmental factors have all been identified as factors contributing to variation in preferred body temperature within and between species in ectotherms (Clusella-Trullas and Chown 2014; Domínguez-Guerrero et al. 2019).

Temperature variations in snakes can be observed in species, sex, size, and seasons. (Pearson et al. 2003). Snakes' body temperature significantly impacts almost every aspect of their ecology; snakes are exclusively cold-blooded, and their body temperature is derived primarily from environmental sources (Himes et al. 2006). Since atmospheric temperature fluctuates daily and seasonally, body temperature in snakes is also likely to fluctuate (Himes et al. 2006). The environmental variables that influence snake activity are known to differ between species (Brown and Shine 2002). However, the temperature is an inevitable variable that drives the ecological, behavioural, physiological and genomic processes in snakes, that are poikilotherms (Huey 1982; Passek and Gillingham 1997; Stahlschmidt et al. 2015; Dayanada et al. 2021; Yan et al. 2022). Similar to temperature, humidity is also an

essential factor in the biology of pythons. Temperature and humidity have been shown to influence brooding behaviour and nest site selection in pythons (Stahlschmidt et al. 2011). The nesting temperature and humidity in snakes are maintained higher than the environmental temperature and humidity (Dolia et al. 2023). Habitat preference is governed by thermal and humid characteristics, which may influence the activity of a species (Martinez 2020). Even though the pythons are ectotherms, they are still capable of raising their body temperature by shivering that can be up to 32-33 °C, almost 7°C above ambient temperature. This can be achieved by repeated shivers up to 50 per minute, each shivering consists of a series of twitching the muscular contractions of the entire body (Harlow and Grigg 1984; Ramesh and Bhupathy 2010). Individual temperature differences have also been reported based on gender and size. Rapid temperature changes are known in smaller males than larger females (Gibbs and Falls 1979). The size of reptiles has been known to influence its ecology and population dynamics in relation to the variables (Bryant et al. 2012). Body temperature effectively affects all physiological and biochemical processes, and the temperature sensitivity of many body functions has been studied in extensive detail in ectotherms (Pörtner 2002; Pörtner 2010)

Indian rock pythons are huge-bodied ambush predators, and they are non-venomous snakes with adult snout-vent lengths ranging from 6-8 m (Bhupathy 1990). They prefer to inhabit estuarine mangrove forests, arid scrub jungles, rain forests, and grasslands, and most of their prey items are warm-blooded (Whitaker and Captain 2004). Seasonality tends to affect their activity in northern India. At semi-arid conditions, their activity pattern was reported to be unimodal during the winter and bimodal in the spring and summer (Bhatt and Choudhury 1994). The

IUCN has considered it in the Near Threatened (NT) category (Aengals et al. 2021), it is also listed as endangered in the United States Endangered Species Act (U.S.ESA) (Obst et al. 1988; Murphy and Henderson 1997). The presence of Indian rock python has been reported in Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka.

In this study, we have attempted to test how pythons' body temperatures are being affected by environmental variables in general and in different seasons. Additionally, we examined potential differences in body temperature based on sex and size.

This study will aid in understanding the temperature requirement of this ectotherm for the first time in the wild. This would be a baseline study that reveals the temperature requirements of this species in tropical climatic scenario.

7.2. Materials and methods

7.2.1. Study sites' ambient conditions

Environmental air temperatures were logged hourly using temperature and humidity loggers (HOBO; Onset Computer Corporation) placed at a location of the study site. Data was obtained between 2018 and 2019. The Hotemp loggers were attached to a vertical stake. They were positioned approximately 1 to 1.5 m from the ground. The data logger was fixed inside a PVC pipe (Fig.7.1) to prevent rain from damaging the device or direct solar radiation. The mean air temperature for the Moyar valley forest averaged $29.03 \pm 3.65^{\circ}\text{C}$ in summer and $25.92 \pm 3.65^{\circ}\text{C}$ in monsoon, and $26.62 \pm 3.82^{\circ}\text{C}$ in post-monsoon (averaged between 2018-2020). Similarly, the seasonal average relative humidity in monsoon was $81.35 \pm 18.12\%$, post-monsoon $64.57 \pm 18.93\%$, and summer $65.31 \pm 18.38\%$.

7.2.2. Surgical method

Fourteen Indian rock pythons were radio-tracked between 2018 and 2020 (Vishnu et al. 2023). Only five individuals' iButtons were recovered with data (iButtons are the thermocrone data loggers implanted along with radio transmitter for obtaining the body temperature of pythons); the rest were corrupted due to battery loss. The recapturing of individuals was delayed due to COVID-19 lockdown. The average body mass (Mb) of these five pythons was 21.88 ± 10.65 Kg (range: 10.15–32 Kg), and average total length (TL) was 336.9 ± 65.7 cm (range: 268 – 412 cm). The thermal biology of these animals was examined in the following two ways: 1. Temperature-sensitive radio transmitter data from Temperature-sensitive radio transmitters (Holohil Systems Ltd) that were surgically implanted into the coelomic cavity using a surgical technique under isoflurane gaseous anaesthesia by the chief veterinarian (Vishnu et al. 2023). After one week of post-surgical care, the pythons were released back into the forests. Pythons were radio-tracked using a three-element Yagi aerial antenna and receiver (R-1000 Telemetry Receiver; Communications Specialists, Inc., USA).

7.2.3. Transmitter and iButton preparation procedure

The iButtons were activated at one hour interval with iTemp software and later attached to the posterior parts of the transmitters with super glue. They covered the entire set with melted beeswax and moulded it properly (Fig. 7.2); this was done to avoid infection. later the Isoflurane gaseous anaesthesia was given to the pythons and the transmitter was placed intraperitoneally (Reinert and Cundall 1982). After the study, the transmitters were recovered from all the pythons successfully (Fig.7.2)



Fig. 7.1. Deployment of Hobotemp in the field site

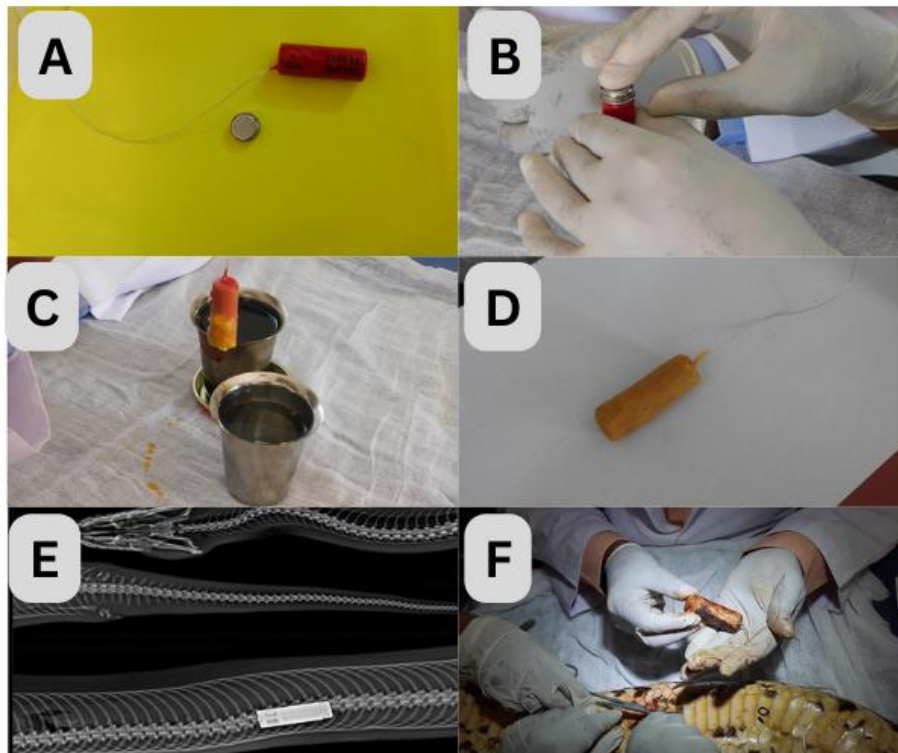


Fig. 7.2. Surgical implantation procedure in python

A Holohill VHF transmitter with iButton; B. Attaching the iButton to the posterior part of the transmitter; C. Dipping the transmitter into melted beeswax, On the left tumbler melted beeswax and to the right tumbler cold water; D. Transmitter after being smoothed with a blade; E. Radiographic image before transmitter retrieval; F. Successful retrieval of transmitter. Beeswax coating can be helpful to avoid pain from the sharp edges of iButtons.

7.2.4 Statistical analysis

Data analysis and visualization were carried out using Excel and RStudio software. Linear models (lm) and the ggplot2 package were used for data analysis, visualization, and interpretation.

i) The influence of environmental variables on python body temperature

To predict the effect of the Environmental variables on the python body temperature, we have run a correlation test using the linear model (lm). The correlation was run between the Python body temperature in response to environmental variables such as atmospheric temperature and relative humidity.

ii & iii) Response of python body temperature to seasonality and individuality of python

To establish any variation in the python body temperature due to seasonal changes, was determined using a comparative analysis between the monsoon, post monsoon and summer period using ANOVA and Tukey's HSD. Similarly, the effect of individuality of the pythons and the sex of the python on their body temperature was also determined using the ANOVA and Tukey's HSD.

7.3. Results

i) Influence of environmental variables in python body temperature

Both the environmental variables (Atmospheric temperature and Relative humidity) are found to be having significant in maintaining the python body

temperature ($p < 0.001$). Body temperature of the python was found to be having a positive response to the atmospheric temperature and a negative response towards the relative humidity, ie. with the increase in atmospheric temperature the python body temperature is increasing and with increase in relative humidity the python body temperature is reducing. The humidity is playing a crucial role in python body temperature regulation.

ii) Response of python body temperature to seasonality

We have the details of five individuals consisting of four females and one male. Also, IP3, a female, had data for only one season. There was difference in the python body temperature in three seasons, monsoon, post-monsoon and summer (ANOVA: $F(2, 5118) = 2770, p < 0.001$). From the 5118 hrs of the data recorded in the monsoon, the average temperature and SD was 27.8 ± 2.2 (Tukey's HSD $p < 0.004$), 6335 hrs of data from post monsoon the average was 27.7 ± 2.7 (Tukey's HSD, $p < 0.001$) and 5267 hrs of data from summer season showed having an average of 29.9 ± 2.2 (Tukey's HSD, $p < 0.001$) respectively. Which indicating that in the three seasons the python body temperature varied according to the surrounding atmospheric temperature (Fig.7.3). The body temperature is also found to be varying with different seasons. In summer the body temperature was different for each python (Tukey's HSD, $p < 0.001$), In post-monsoon and monsoon there was significant difference between three female pythons (Tukey's HSD, $p < 0.001$) but, there was no variation between two pythons (Tukey's HSD, $p < 0.93$) (Fig. 7.4).

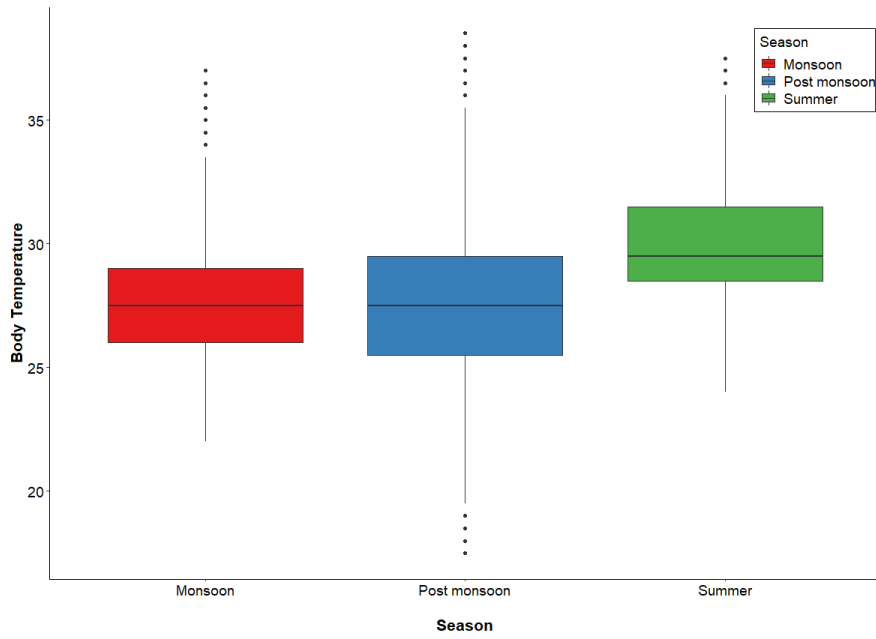


Fig. 7.3. Python body temperature in various seasons (Monsoon, Post-monsoon and Summer)

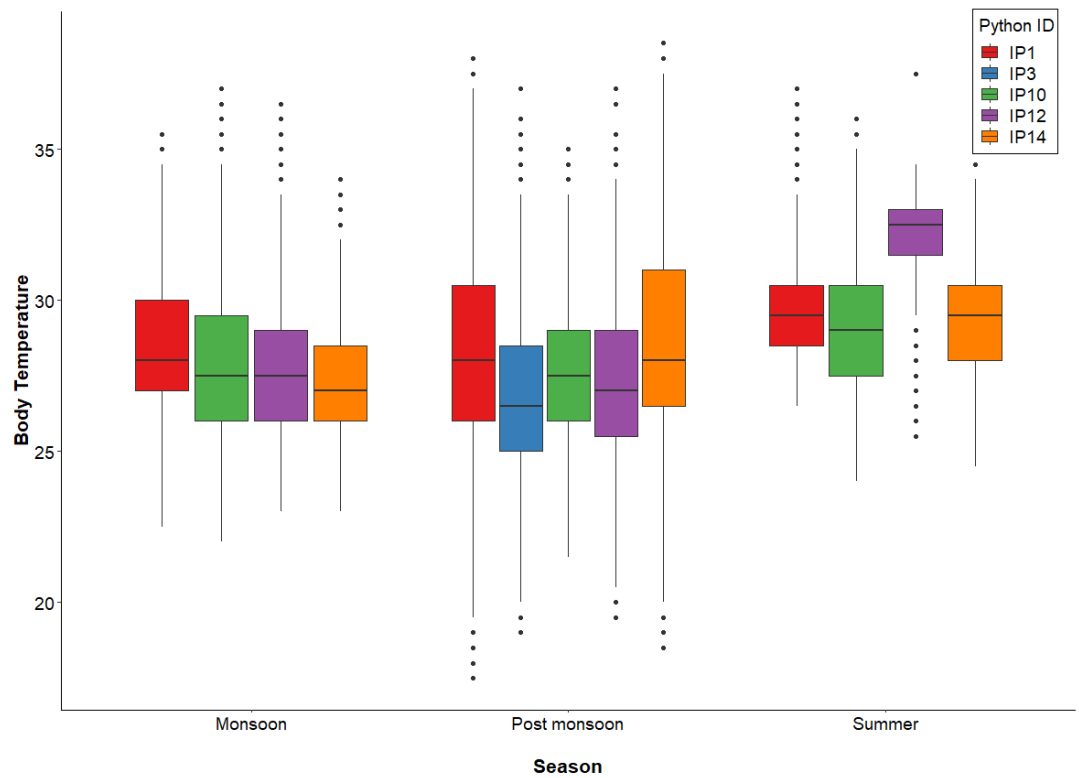


Fig. 7.4. Python body temperature variation in various seasons with respect of individual pythons

iii) Response of python body temperature in response to individual python & sex

Within the five individual pythons studied, there was difference in the body temperature (ANOVA: $F(5, 5113) = 290.5$, $p < 0.001$), which indicates a shift in the body temperature for each python (Tukey's HSD, $p < 0.001$) other than between two female pythons (Tukey's HSD, $p < 0.06$).

Table. 7.1. Morphometry and seasonal temperature of Indian rock pythons

Individual ID	Sex	Total length (cm)	Body mass (kg)	Mean seasonal temperature in pythons ($\bar{X} \pm SD$) °C		
				Monsoon	Post-monsoon	Summer
IP1	Female	412	32	28.42±2.12	28.32±3.36	29.58 ± 1.85
IP3	Female	350.5	11.05	-	26.85±1.69	-
IP10	Male	268	10.15	29.12±2.43	27.32±2.09	29.12 ± 2.43
IP12	Female	384	31.4	27.75±2.24	27.27±2.36	31.76 ± 2.91
IP14	Female	270	24.8	27.44±1.77	28.58±3.07	29.35 ± 1.69

Same temperature between these two female pythons may be due to presence of similar habitat with nearby water body in its home-range. There is significant difference between the sexes of the python (male and female) in temperature (ANOVA: $F(1, 4) = 395$, $p < 0.001$).

7.4. Discussion

From the study, we found that the environmental variables, such as atmospheric temperature and relative humidity, are significant in maintaining the python body temperature. The body temperature of the python was found to have a positive response to the atmospheric temperature and a negative response towards the relative humidity, i.e., with the increase in atmospheric temperature, the pythons' body temperatures increased. With an increase in relative humidity, the pythons' body temperature decreased. Humidity plays a crucial role in python body temperature regulation. It is established that, temperature and relative humidity are the essential variables in maintaining and regulating the python body temperature.

A study on Rattlesnakes in Texas by Borrell et al. (2005) observed that head-body temperature increased with air temperature but declined significantly at higher relative humidities. Whereas a study by George et al. (2015) observed that air temperature and relative humidity differentially affect the activity patterns of a north American colubrid, which is an important predator and observed the increased nest predation rates with warmer temperatures.

Apart from the environmental variables, seasonality also influences the body temperature of Indian rock pythons. The body temperature of pythons changed according to the three seasons, with the summer season recording higher body temperature than monsoon and post-monsoon. Thus, seasonality is a major factor that affects the snakes in different aspects. Seasonal activity patterns in several temperate snake species have been described (Gibbons and Semlitsch 1987; Durner and Gates 1993; Carfagno and Weatherhead 2008; Sperry et al. 2008). Snakes were twice as likely to move during high-humidity periods as during low-humidity periods (George et al. 2015). Also, studies report that moisture can affect habitat selection and activity patterns of snake species (Daltry et al. 1998; Moore and Gillingham 2006; Howze and Smith 2012).

Daltry et al. (1998) observed that the frequency and distance of tagged snakes' movements to new sites were highly positively correlated with ambient relative humidity, but not with rainfall, ambient temperature, or the lunar cycle, according to correlation tests.

During the summer, we found a hike in the body temperature in pythons compared to other seasons (Fig. 7.3). IP12 a female python, showed comparatively higher body temperature than other individuals (Table.7.1). However, it might have been

due to the increased body temperature during the incubation period; even though we do not have any the substantial evidence to prove it. The field monitoring was hampered due to COVID19 lockdown, but studies state that the post-monsoon is the mating season of Indian rock pythons in southern India (Ramesh et al. 2019; Vishnu et al. 2021), summer season is the incubation and hatching period in the study area. The forest officials recovered eggshells and hatchling at the end of summer month (Ramesh Forest guard *person. comm*). Pythons can raise their body temperature beyond the atmospheric temperature by shivering the body, particularly during the incubation period (Harlow and Grigg 1984; Ramesh and Bhupathy 2010).

Also, they can store sperm and utilise it when a favourable season appears for hatching. Studies show that the female can store sperm until she oviposits, at which time fertilization occurs (Adolph and Geber 1995; Groot et al. 2003). Similarly, parthenogeny is also reported in snakes, especially in pythons (Groot et al. 2003; Booth and Schuett 2016; Shibata et al. 2017).

During the winter, the pythons remain in some safe underground, which may extend up to March. This indicates a short hibernation behaviour that lasts until the temperature rises again (Murphy and Henderson 1997; Ramesh and Kamalakannan 2020); however, in Moyar river valley, year-round activity can be observed in the species due to higher temperature than in northern India.

The habitat preference is governed by thermal and humid characteristics, which may influence the activity of a species. *Python regius* is known to show fluctuating preference according to the changes occurring in humidity level, as although an important variable, the higher or lowest may challenge their survival (Martinez

2020). The importance of maintaining optimal thermal values against the sub-optimal ambient temperatures thus require a habitat preference in snakes (Cox et al. 2018). In the case of oxygen transport in fasting and digesting snakes will be high at increased temperatures; a gradual rise in temperature from 30 to 40°C throughout ten-hour will reflect oxygen uptake, arterial blood pressure, heart rate, and arterial blood gases (Dannie et al. 2014). The preferred body temperature of most snakes, including pythons, is around 30°C (Slip and Shine 1988; Bedford and Christian 1998; Ramesh and Bhupathy 2010), and the upper lethal temperatures of snakes are normally below 42°C (Brattstrom 1965). During the digestion, the temperature rises to 30 – 40°C and the oxygen uptake rate increases (Dannie et al. 2014).

During the study, we found that the body temperature of individuals may vary according to the seasons, which may be largely due to the post-feeding digestion phase and incubation period. The post-feeding periods in pythons have observed to have body temperature higher than the atmospheric temperature (Vishnu et al. 2024). Many snakes select higher temperatures post-feeding to accelerate digestion and increase efficiency (Regal 1966; Harwood 1979; Naulleau 1983; Christian et al. 1984; Sievert and Andreadis 1999; Blouin-Demers and Weatherhead 2001; Tattersall et al. 2004; Bhupathy et al. 2012). However, individual differences in body temperature have also been reported based on gender and size in studies. Rapid temperature changes are known in smaller garter snake males than in larger females (Gibbs and Falls 1979). After the feeding, a few observations noticed that the Indian rock pythons were found to lie inside the river or water bodies to regulate the body temperature (Vishnu et al. 2024).

7.5. Conclusion

Temperature and humidity are very important ambient factors for the survival and well-being of Indian rock pythons. Based on the various needs, their temperature changes. Minute climatic changes or human-induced changes may cause an alteration in their physiology. These findings are essential for conservation management strategies, as they provide insights into the reptile thermal biology in general and python's thermoregulatory behaviour in particular, which can inform the development of effective management plans to conserve this species in this region. The minimum and maximum temperature requirements are important considerations, as road deaths among thermoregulating pythons on tar roads have occurred. Therefore, constructing black heat-radiating surfaces in their habitat can be beneficial for their successful conservation, as it aids in thermoregulation during the monsoon.

About 21.3% (n = 137) of people reported livestock loss due to pythons in Moyar river valley (Ramesh et al. 2020). Additionally, the same study revealed that 86.5% of respondents in the study area had strong negative perceptions of snakes (Ramesh et al. 2020). Pythons were one among the most frequently sighted snake species by the respondents, accounting for 17% (n = 179) of the sightings (Fig. A.1). Moreover, the majority of the respondents, 61.2% (n = 394), perceived snakes as a significant problem or threat to their life (Ramesh et al. 2020).

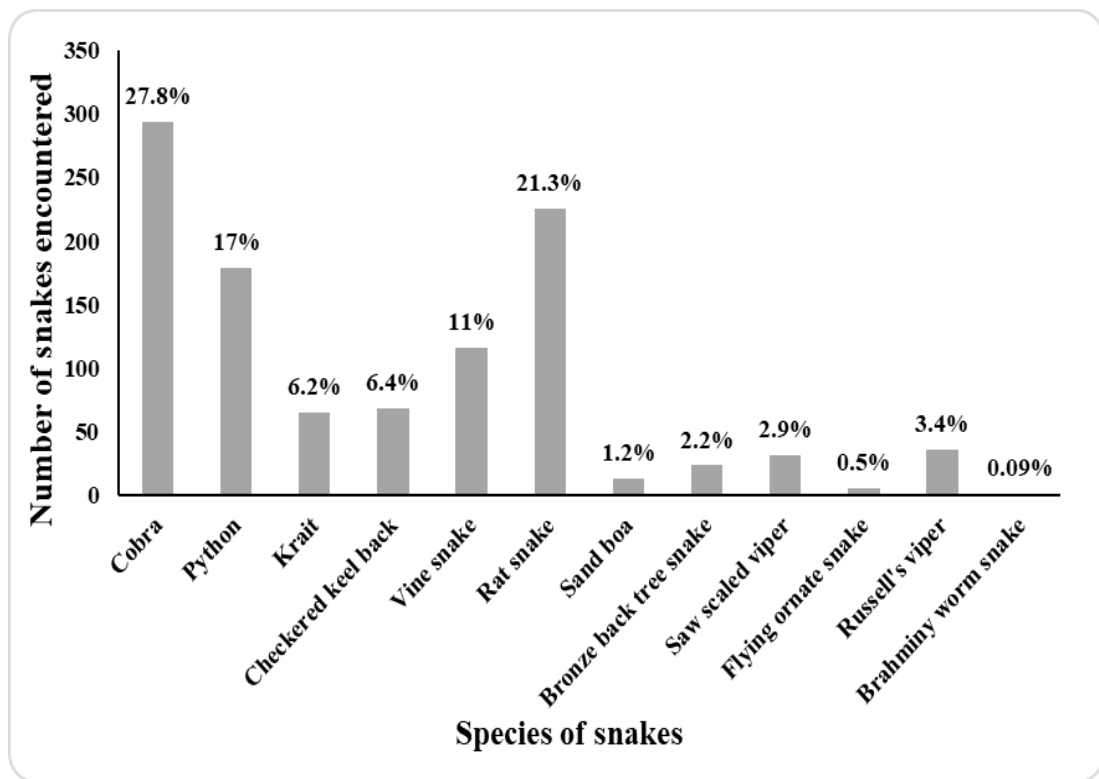


Fig. A.1. Snake species as encountered by respondents in the study area (Source: Ramesh et al. 2020)

In this context, the following suggestions are derived for successful translocations of pythons.

- 1) **Try releasing the rescued pythons at longer distances, possibly greater than 20 km**
- 2) **Make efforts to conserve the microhabitats:**
 - **Habitat Preservation:** - Protect and preserve the natural habitats where pythons are found.
 - **Reforestation and Habitat Restoration:** - Restore degraded habitats by planting native vegetation and trees that are essential for python survival. This helps recreate suitable microenvironments for pythons.
 - **Reduce Human Disturbance:** - Implement measures to minimize human interference in python habitats, such as restricting development, enforcing regulations against poaching, and controlling tourism activities that can disrupt their natural behavior.
 - **Education and Awareness:** - Raise awareness among local communities, stakeholders, and the public about the importance of python microhabitats and the role these snakes play in the ecosystem. Promote responsible tourism and behavior around python habitats.
 - **Research and Monitoring:** - Conduct scientific research for the better understanding of python ecology, behavior, and habitat requirements. Regular monitoring of python populations helps to assess the effectiveness of conservation efforts.
 - **Habitat Connectivity:** - Establish corridors or connectivity between fragmented python habitats to enable gene flow and migration, which is crucial for maintaining healthy populations.
 - **Engage Local Communities:** - Involve local communities in conservation efforts by providing alternative livelihoods and incentives for protecting python

habitats. Including and collaborate with them in conservation planning and management.

- Collaboration and Partnerships: - Work together with governmental agencies, non-governmental organizations, and international partners to pool resources and expertise for effective python habitat conservation. Conserving python microhabitats is essential not only for the well-being of these snakes but also for maintaining biodiversity and ecosystem balance.
- 3) Ensuring the availability of water at the release site while translocating pythons is important for their survival and well-being. Here are some steps to achieve this.
- Site Selection: - Choose a release site that has a natural water source nearby, such as a river, pond, lake, or other bodies of freshwater. Ensure that the site is suitable for the python in terms of different ecological and habitat requirements.
 - Pre-Release Assessment: - Conduct a thorough assessment of the release site to ensure that the water source is reliable and provides the necessary conditions for the pythons to thrive. This includes checking for water quality, availability throughout the year, and the presence of suitable prey.
 - Climate and Season Considerations: - Be mindful of the climate and season when planning the translocation. Ensure that the release site has water available during the specific time of year when the pythons are released. Avoid releasing them during droughts or extreme weather conditions when water sources may dry up.

- **Monitoring Water Levels:** - Continuously monitor water levels at the release site before, during, and after the translocation process. This will help to ensure the availability of water and identify any changes that may affect the pythons.
 - **Create Artificial Water Sources:** - In some cases, it may be necessary to create artificial water sources, such as small ponds or water troughs, near the release site. These can provide a temporary water source for the pythons until they get advantage to their new environment and locate natural water sources.
 - **Provide Access:** - Ensure that the pythons have easy access to the water source at the release site. Avoid placing barriers or obstacles that may prevent them from reaching the water.
 - **Release Site Preparation:** -Before releasing the pythons, prepare the release site by removing any potential hazards or threats to the snakes. This includes removing invasive species, minimizing prevailing threats if any, securing the area against predators, and ensuring there are suitable hiding places near the water. Ensure the availability of prey at the release sites. This can be achieved by analyzing camera trap data collected by researchers, NGOs, or forest departments, among others.
- 4) Avoid python release close to the human habitations
 - 5) Raise awareness among the villagers about venomous and non-venomous snakes.
 - 6) Provide information and awareness about the Livestock Compensation Scheme.
 - 7) Educate people about the legal aspects concerning the killing of scheduled species.
 - 8) Recommend the implementation of improved medical facilities free of cost

- 9) Construct Black heat-radiating structures in the habitats of pythons to avoid roadkill during rainy days (It helps thermoregulation during rainy days, and also increase the possibility of reducing the road mortality).

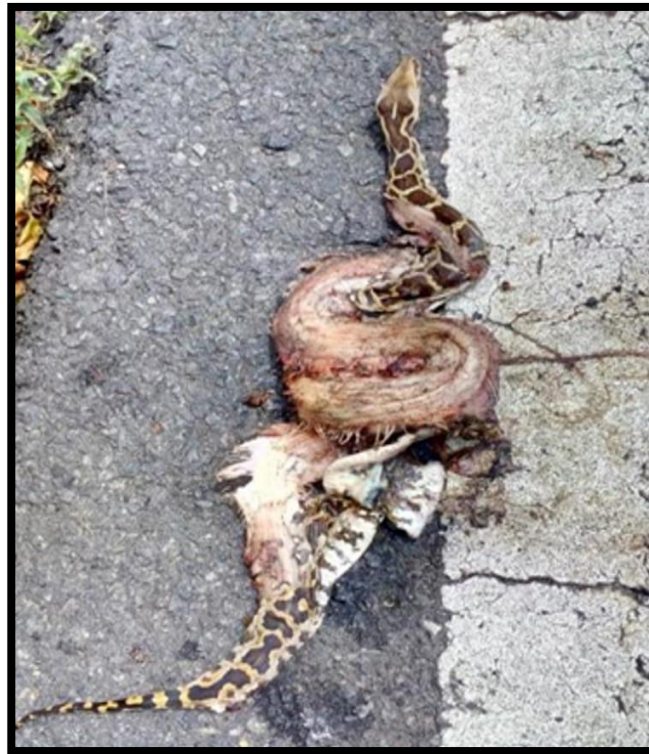


Fig. A.2. Road mortality of Indian rock python at Bannari road, Sathyamangalam Tiger Reserve.

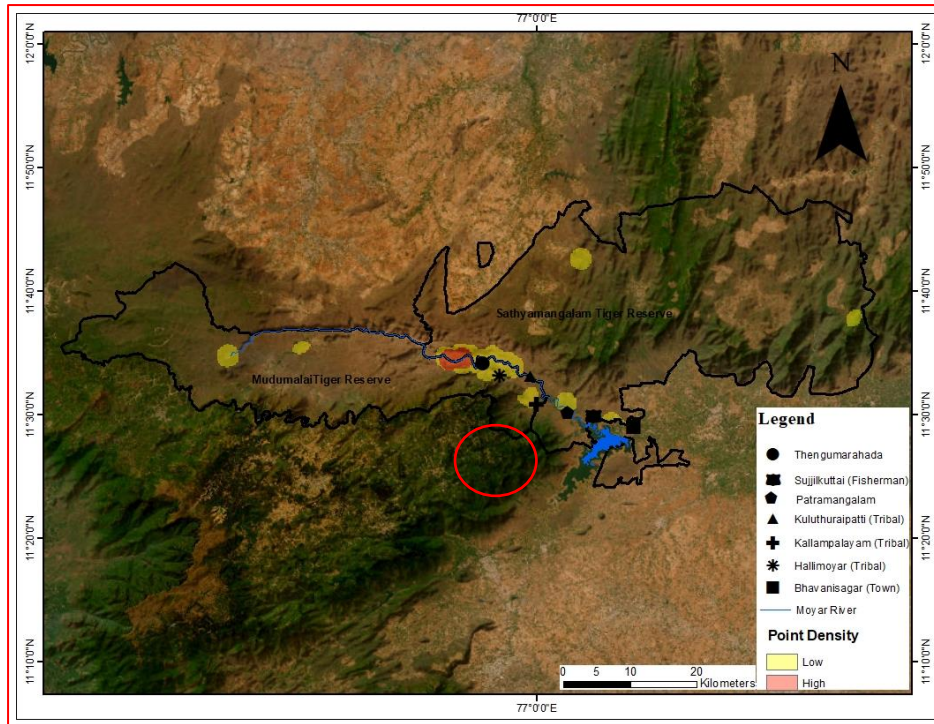


Fig. A.3. Point density map of opportunist survey locations

The circled area has a higher presence of Pythons with significant rescue activity. We recommend the forest department to adopt a two-fold approach: Firstly, if the pythons are not causing conflicts, it is advisable to leave them undisturbed. Secondly, in case of high conflicts, the pythons should be relocated to distant areas within the core forests, following the proposed suggestions.

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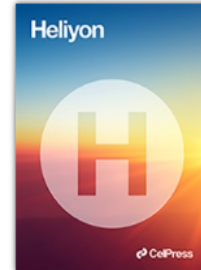
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OPEN Home range ecology of Indian rock pythons (*Python molurus*) in Sathyamangalam and Mudumalai Tiger Reserves, Tamil Nadu, Southern India

C. S. Vishnu¹, Benjamin Michael Marshall², Chinnasamy Ramesh^{1✉}, Vedagiri Thirumurugan¹, Gautam Talukdar¹ & Abhijit Das¹

The Indian rock pythons (*Python molurus*) are classified as a near-threatened snake species by the International Union for the Conservation of Nature and Natural Resources (IUCN); they are native to the Indian subcontinent and have experienced population declines caused primarily by poaching and habitat loss. We hand-captured the 14 rock pythons from villages, agricultural lands, and core forests to examine the species' home ranges. We later released/translocated them in different kilometer ranges at the Tiger Reserves. From December 2018 to December 2020, we obtained 401 radio-telemetry locations, with an average tracking duration of (444 ± 212 days), and a mean of 29 ± SD 16 data points per individual. We quantified home ranges and measured morphometric and ecological factors (sex, body size, and location) associated with intraspecific differences in home range size. We analyzed the home ranges of rock pythons using Auto correlated Kernel Density Estimates (AKDE). AKDEs can account for the auto-correlated nature of animal movement data and mitigate against biases stemming from inconsistent tracking time lags. Home range size varied from 1.4 ha to 8.1 km² and averaged 4.2 km². Differences in home range sizes could not be connected to body mass. Initial indications suggest that rock python home ranges are larger than other pythons.

An animal's space use primarily reflects its resources' spatial availability¹, whether those resources are shelter, food, mates, or other necessities. Home range quantification is one of the primary components in animal habitat-resource selection studies that can draw behavioral-ecological inferences across spatiotemporal scales². Spatial-habitat requirements and accurate natural history information are essential for developing adaptive conservation and management plans³. The foraging patterns, migration and dispersal, and breeding success are all fundamental parameters directly associated with animal space use^{4,5}. Home range size can correspond with the animal's body size^{6,7}, where larger snakes tend to have larger ranges⁸.

Like many groups, snakes are facing a widespread decline worldwide⁹, so collecting information on home range, habitat use, and movement patterns is essential to highlight areas where human-snake confrontation needs to be reduced. Due to human activities, suitable habitat is becoming fragmented or isolated; therefore, species with low dispersal potential are highly vulnerable to local extinction¹⁰. A thorough understanding of spatial and temporal habitat requirements can aid resource managers in protecting species and the specific landscape features on which they depend¹¹. A critical element in species conservation is knowledge concerning habitats^{12,13} as well as the movement and activity of animals within suitable habitats^{14,15}. In addition, knowledge of specific resources and microhabitats used by species is vital for effective species management^{16,17}.

Radio-telemetry is an essential tool for studying snakes because of snakes' low detectability^{18,19}; with radio-telemetry we can gain an insight into their requirements. The application of radio-telemetry allows for consistent determination of the snake's location that, in turn, aids in identifying the habitat preference of snakes, frequency of its movement, distance moved, and home range²⁰.

Like many snakes, the rock python's ecology is only partially understood. Only a few studies on *P. molurus* have taken place in India; the first-ever study on the general ecology and population estimation of this species

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Microhabitat Use of Indian Rock Pythons (*Python molurus*) in the Moyar River Valley, Tropical India

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Abstract: The knowledge of microhabitats used by a species is essential for its effective conservation and management. This study aimed to quantify the microhabitat use of Indian rock pythons (*Python molurus*) in the Sathyamangalam and Mudumalai Tiger Reserves (STR & MTR), Tamil Nadu. Fourteen pythons were captured through intensive search and opportunistic methods from STR, MTR, and nearby villages and then radio-track between 2018 and 2020. The various microhabitats were categorized and quantified based on sightings of the radio-tagged pythons. A total of 401 microhabitat locations were collected and classified into eight categories: burrows, dead fallen trees, dry bushes, green bushes, trees, open areas, rock crevices, and water. The study results showed that the microhabitat use of male and female pythons was significantly related. The number of sightings was converted into proportions, revealing that dry and green bushes were the most preferred microhabitats by pythons. This study provides valuable insights into the microhabitat preferences of *P. molurus* in tropical climatic conditions and can help in the formulation of effective policies and measures to protect this species and its micro-habitats.

Keywords: Indian Rock Pythons, *Python molurus*, Bushes, Microhabitat, Radio-transmitter, Moyar river valley

Snakes are known to inhabit diverse habitats and microhabitats, which include terrestrial, aquatic, and arboreal. Microhabitats differ from place to place, including stone, burrows, paddy fields, streams, rock, leaf litter, open forests, forest edges, and water bodies (Lalremsanga et al 2011, Rahman et al 2014). Among pythons, different species have an affinity over various landscapes, habitats, and microhabitats. Indian rock pythons (*Python molurus*) are known to inhabit a wide range of habitats across their distribution range. *P. molurus* occupy scrub jungles, moist forests, evergreen forests, grasslands, and mangrove ecosystems and are water dwellers; thus, they prefer zones with water bodies like swamps and riparian habitats (Sharma 2003, Whitaker and Captain 2004). Pythons also thrive in rocky hills (Hunter et al 2018, Babar et al 2019).

The microhabitat selection in *P. molurus* is also diverse. They are known to use burrows, tree hollows, marshes, wet rocky ledges along the pools and streams, thickets found in the mangrove, bushes, dense vegetation clumps, large rotten logs, treetops, water reeds, and leaf litters, caves, crevices, and ruins (Sharma 2003, Whitaker and Captain 2004, Mukherjee et al 2017, Babar et al 2019). However, the microhabitat usage of *P. molurus* in the tropical climate regions have not been studied yet. Burmese pythons (*Python bivittatus*) are the sister species of *P. molurus*; in general, they are known from South East Asia, inhabiting forests, lowlands of the tropics, grasslands, agricultural lands, and aquatic habitats (Barker and Barker 2008, Cota 2010, Stuart

et al 2012, Rahman et al 2014). Walters et al (2016) found the *P. bivittatus* to show a negative selection over freshwater bodies but preferred canopy-associated coniferous forests. However, most of the studies show *P. bivittatus* to have a positive selection towards water or aquatic habitats irrespective of the native population or invasiveness in a different geographical area (Cota 2010, Stuart et al 2010, Rahman et al 2014, Hunter et al 2015, Mustascio et al 2017, Conyers and Roy 2021, Smith et al 2021). Therefore, habitat selection is an essential cue in the pythons, and various ecological and climatic factors influence it.

P. molurus is a Schedule I animal of the Indian Wildlife Protection Act 1972. The International Union for Conservation of Nature assessment lists them in the Near Threatened category (Aengals et al 2021). The species was facing population decline due to severe habitat loss and poaching (Babar et al 2019). In this context, understanding the microhabitat use of this species in the tropical climate will support their conservation management from habitat degradation. In this study, quantified the proportion of microhabitat use in the *P. molurus* in the tropical climatic region, Southern India. The study results would help in identifying and conserving natural microhabitats of the study site which can also be supported in identifying suitable translocation sites for rescued individuals from conflict zones.

MATERIAL AND METHODS

Study area: The study was conducted between 2018 and



The Post-feeding Activity of an Indian Rock Python, *Python molurus* (Linnaeus 1758), in the Moyar River Valley, Southern India

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The Indian Rock Python (*Python molurus*), which is widely distributed across India to elevations of 2,000 m asl, also occurs in Pakistan, Nepal, Bhutan, Bangladesh, and Sri Lanka (Smith 1943; Das 2002; Whitaker and Captain 2008; Aengals et al. 2021). These snakes occur in a wide variety of habitats, including estuarine mangrove forests, arid scrub jungles, rainforests, wetlands, drylands, rainforests, and grasslands (Whitaker and Captain 2008; Kamalakannan 2009). With an average adult SVL of 6–8 m, *P. molurus* is a large, heavy-bodied, ambush predator (Bhupathy 1990). Prey consists mainly of homeotherms (Whitaker and Captain 2008), but they also feed occasionally on ectotherms (Bhupathy et al. 2014). Indian Rock Pythons can remain submerged in water for at least half an hour (Sharma 2003; Whitaker and Captain 2008). This species faces severe threats from anthropogenic activities such as habitat degradation and loss, and is listed as Near Threatened (NT) on the IUCN Red List (Aengals et al. 2021). The species is protected under Schedule-I of the Indian Wild Life (Protection) Act–1972 (Government of India Ministry of Law and Justice 1972) and is listed in CITES Appendix I (CITES 2023).

In determining the geographic distribution of ectotherms, temperature stands out as one essential abiotic factor (Cossins and Bowler 1987; Angilletta 2009). Preferred body temperatures of snakes is generally in the range of 25–30 °C (Slip and Shine 1988; Bedford and Christian 1998), and the average critical maximum for snakes is about 40 °C (Brattstrom 1965). Pythons are known to elevate their body temperatures above ambient by means of rapid whole-body shivering, facilitated by muscle twitches, at rates as high as 50/min (Harlow and Grigg 1984). Female Indian Rock Pythons can maintain body temperatures of 32.5 ± 0.78 °C during incubation despite ambient temperatures fluctuating between 9.7 °C above and 6.1 °C below body temperatures (Ramesh and Bhupathy 2010). Such thermoregulatory behaviors

are important for reptiles because of the known interaction between temperature and physiological and biochemical processes in ectothermic organisms (Pörtner 2002, 2010; Clark et al. 2013). Reptiles also are known to use water to thermoregulate and aid in digestion (Meek 1995).

We equipped a female Indian Rock Python with an AI-2 Hohills VHF transmitter (27 g) with an I-button, covered it with beeswax, and positioned the transmitter intraperitoneally in the coelomic cavity (Reinert and Cundall 1982; Ramesh et al. 2019). We observed a feeding event on 13 March 2019 in the Moyar River Valley, and subsequently monitored the individual until 29 March 2019. To understand how body temperature changed during digestion, we collected body temperatures (BT) at one-hour intervals between 1 March and 1 April 2019 and recorded ambient temperatures (AT) using a field-deployed Hobo temperature logger, also at one-hour intervals (Fig. 1).

At 1011 h on 13 March 2019, we found an adult female python that had consumed a large meal and was resting beneath dry brush (Fig. 2). The prey item presumably was a Spotted Deer (*Axis axis*), as we found identifiable pellets nearby. On 17 March 2019, the snake had moved under

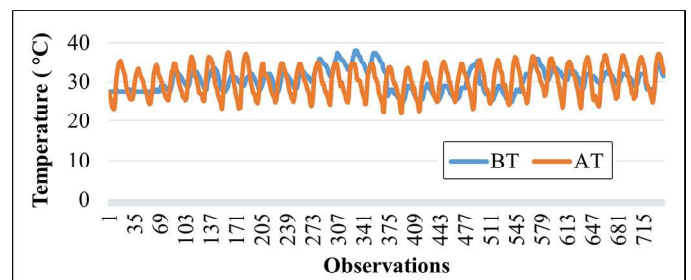


Figure 1. Temperature data of an adult female Indian Rock Python (*Python molurus*) at one-hour intervals from 1 March 2019 to 1 April 2019. Body temperature (BT) is shown in blue and ambient temperature (AT) in orange.



Figure 2. Post-feeding activity of an adult female Indian Rock Python (*Python molurus*): Feeding event recorded on 13 March 2019 (A); three days later on 16 March 2019 in the same area (B); left the area on 17 March 2019 (C); along the bank of the Moyar River on 17 March 2019 (D); again in the water on 21 March 2019 (E); returned to the area where the feeding event occurred on 22 March 2019 (F); again in the water on 23 March 2019 (G) and on 29 March 2019 (H). Photographs by Vishnu C.S.

a recently fallen tree in the middle of the Moyar River (11.57908°N, 76.9025°E). Following the feeding event, the python's body temperature exceeded ambient temperature (Fig. 1) and, during the post-feeding period, the python remained either in the river habitat or in adjacent dense brush. Mean pre-feeding body temperature was 27.56 ± 0.16 °C while mean ambient temperature was 29.52 ± 4.25 °C. Subsequent to ingesting the meal, mean body temperature increased to 35.5 ± 1.93 °C while mean ambient temperature was 30.17 ± 3.42 °C.

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Short Communication

Size Matters: First record of minimum male size at maturity and mating of free-ranging, endangered Indian Python *Python molurus*

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ABSTRACT

Indian python *Python molurus* (Linnaeus, 1758) is one of the world's giant snakes with maximum lengths measured six to eight meters. Nevertheless, information on the size at maturity of *P. molurus* is not available. On February 9, 2019, 12:56 pm, one female and two males were observed during the group mating in Moyar River Valley Landscape, Southern India. We report the first observation on smallest male measuring 198 cm total length, 172 cm snout-vent length and weighing 3.3 kg mated with a radio-tagged larger female. At the end of the mating event everted hemi penis were observed in the male pythons. Our observation on the mating and morphology details of *P. molurus* gives the first glimpse of juvenile the male maturity that representing the youngest known free-ranging matured male of this poorly studied species in its distribution range.

Keywords: Courtship, Life-history traits, Reproduction, Sexual maturity, Snakes, Morphometry.

INTRODUCTION

Indian python *Python molurus* (Linnaeus, 1758) is one of the world's giant snakes with maximum lengths measured six to eight meters (Bellosa, 2003; Reed & Rodda, 2009) with clutch sizes varies from eight to 107 (Daniel, 1983, Ramesh & Bhupathy, 2010). The large size of this species may be its primary ecological adaptation (Reed & Rodda, 2009). Despite the vast geographic distribution, data on biology, patterns of growth, maturation, reproduction, and natural history limited in *P. molurus*. Mainly, mating records of this species are scanty due to secretive habits (Ramesh *et al.*, 2019). In India, the mating of *P. molurus* takes place between December and February (Ramesh *et al.*, 2019, Ramesh & Bhupathy, 2010).

Size and age at maturity are dominant life-history traits, as they shape lifetime fecundity. These constitute the outcome from complex interactions among environmental pressures and individual characteristics (Fornasiero *et al.*, 2016). The maturity of juveniles is challenging to measure in the wild populations, and thus they are rarely evaluated, especially in reptiles due to the secretive nature of young ones (Fornasiero *et al.*, 2016). *Python molurus* is a large, heavy-bodied non-venomous ambush snake (Bhupathy, 1990; Bhupathy *et al.*, 2014); found in large, undisturbed stretches of diverse habitats in the Indian sub-continent (Ramesh, 2012, Whitaker, 1993; Bhupathy & Vijayan, 1989). *Python molurus* listed as Schedule I -species of the Indian Wildlife Protection Act-1972. The IUCN Red List of Threatened Animals has yet to assess this species status. This snake also included under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) list after severe habitat loss

and abuse by the skin, pet and meat trade (Whitaker, 1993). Combined with rapid developmental activities in forests, making this species living in fragmented environments across the country. Hence, immediate attention is required to obtain sufficient ecological data to prepare plans to protect this endangered species (Koo *et al.*, 2018).

Python molurus are generally solitary species, combined in pairs only during mating (Ramesh *et al.*, 2019). The rate of growth in nature is not known, and records of growth in captivity vary greatly (Acharjyo & Mishra, 1976; Acharjyo & Mishra, 1980; Rathinasabapathy & Kalaiarasan, 1993; Vyas, 1995, 1998). *Python molurus* growth rates are obviously influenced by the conditions under which the snake lives (Smith, 1943). Females appear to attain significantly larger body sizes than conspecific males in most python species (Shine and Slip, 1990) and this statement appears to be valid for the *P. molurus* (Ramesh, 2012). The complete reproductive biology of this species is little known under natural condition in its native distribution range (Ramesh, 2012; Ramesh & Bhupathy, 2010). Particularly, no data on the minimal size for male sexual maturity exist from the wild *P. molurus*.

The pythons reach sexual maturity in three years in captivity (Acharjyo & Mishra, 1980; Vyas, 1995, 1998). Captive individuals attain sexual maturity when it is of two to three years provided if it can reach a suitable body weight (Bhupathy, 1993). Acharjyo & Mishra (1980) presumed that the male pythons require a long time to reach sexual maturity than females. Vyas (1998) reported from captive observation that male pythons mature when it reached about 235cm total body length with weight about 5.2 kg and 67.09 month after hatching. Perhaps, it is not clear as to what could be the

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