ECOLOGY AND CONSERVATION OF PIT VIPERS ALONG THE WESTERN GHATS (GOA)

THESIS
Submitted to
GOA UNIVERSITY

FOR THE AWARD OF DEGREE OF

DOCTOR OF PHILOSOPHY IN ZOOLOGY

BY
NITIN S. SAWANT

DEPARTMENT OF ZOOLOGY
GOA UNIVERSITY
GOA 403 206

FEBRUARY 2011

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DECLARATION

I hereby declare that the work reported in the present thesis entitled "Ecology and Conservation of Pit Vipers along the Western Ghats (Goa)" is solely carried out by me under the supervision of Dr. S. K. Shyama, Department of Zoology, Goa University, Taleigao, Plateau Goa. To the best of my knowledge, the present study is the first comprehensive work of its kind from the area mentioned. No part thereof has been submitted for any other degree or diploma of this university or any other University/Institute.

Place: Goa University

Date: 16\02\2011

(Nitin S. Sawant)

Research student

CERTIFICATE

This is to certify that the thesis entitled "Ecology and Conservation of Pit Vipers along the Western Ghats (Goa)" submitted by Mr. Nitin S. Sawant for the award of the degree of Doctor of Philosophy in Zoology, is based on his original and independent work carried out by him during the period of study, under my supervision.

The thesis or any part thereof has not been previously submitted for any other degree or diploma in any University or Institute.

16/2/11

(S. K. Shyama)

Research Guide

Place: Goa University

Date: 16/2/11

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CHAPTER 1

INTRODUCTION

General introduction of snakes

The snakes belong to Sub-order Serpentes of the Order Squamata of Class Reptilia which includes, besides the living Sauria (Lizards), the extinct Pythonomorpha, Aigialosauria and Dolichosaurio. Snakes are fairly abundant reptiles but their presence is usually not felt because of their nocturnal propensity. They occupy almost all the habitats, but they are not found in arctic and in cooler climates. Their abundance and importance in the human society is fairly well reflected in the Hindu mythology. Snakes can be defined as exothermic (poikilothermic), carnivorous vertebrates characterized by having greatly elongated body with tail of moderate and variable length, devoid of limbs and girdles (except in Pythons and Boas where vestige of pelvic girdle and hind limbs are present). Body is covered with overlapping scales which are not granular; eyelids are fused and form a transparent spectacle over the eye; tympanum and urinary bladder are not present; tongue is long, narrow and forked which is retractile in to a basal sheath and the rami of mandible are united by extremely united tissue without forming any symphysis. The articulation of two rami of a mandible in snakes is known as an intermandibular zone of weakness and bears a great significance in the taxonomy of snakes. Technically the snakes are mainly identified by the structure and arrangement of their scales. In all snakes, the scales usually retain their characteristics throughout life (Smith, 1943). Terrestrial and aquatic habitats of the world host around 3273 species of snakes belonging to 364 genera and 12 families (Sharma, 1991). India too harbours numerous species (275) of snakes (Whitaker and Captain, 2004) with drastic variation in their size ranging from 100 mm (worm snake) to 6 m long python. These species comprise capable swimmers, fast runners, accomplished burrowers, tree dwellers and perfect gliders.

Systematic position and description of pit vipers

Pit vipers belong to:

Class: Reptilia

Order: Squamata

Suborder: Serpentes

Family: Viperidae

Sub-family: Crotalinae (Smith, 1943)

Viperidae is the highly evolved family of snakes and includes the venomous snakes. They are easily recognized by the broad, flat and triangular head, narrow neck, elliptical eye pupil and thick body with a short tail which is prehensile in some. The head is covered with few large shields as well, a large number of irregularly arranged small scales. The pattern consists of a series of blotches or wavy bands, both on the dorsum and belly. The most distinctive characteristic of this family is a pair of short maxillae to each of which is attaching a single long fang. Each maxilla is hinged so that the fangs can be folded back when not in use (Solenoglyphs). Vipers are mostly terrestrial or arboreal but there are a few burrowing species and some are semi-aquatic. Many are well camouflaged snakes that ambush their prey as they are sluggish creatures and cannot chase their prey. Most of the species are viviparous, but a few lay eggs (Engelmann and Obst, 1984).

Pit vipers are so called due to the presence of a prominent heat sensitive pit. The 'pit' is a noticeable depression situated on the head of a pit viper between the nostril and the eye. It is a heat sensitive organ and helps the pit vipers in detecting the prey even in total darkness.

Diversity of pit vipers in Indian Peninsula

Globally the subfamily Crotalinae comprises of 21 genera, which are distributed throughout America and South Asia. Old world pit vipers include the ecologically diverse genus *Trimeresurus*, with 28 species distributed throughout much of the Asia, India and numerous Islands in Pacific Ocean (Bhide, 2001). There are 20 species of pit vipers found in India of which 7 are endemic to India out of which 5 species are reported from Western Ghats, (Whitaker and Captain, 2004). Three species of pit vipers are found in Goa Viz. *Trimeresurus malabaricus, T. gramineus* and *Hypnale hypnale* (Khaire, 2006; Pradhan, 2008). Out of these three species *T. malabaricus* is endemic to the Western Ghats, *T. gramineus* is reported from Eastern and Western Ghats and *H. hypnale* is found in the Western Ghats and Sri Lanka (Smith 1943; Whitaker 1978). *Hypnale hypnale* has been recorded mainly from the southern part (up to about 16^0N) of the Western Ghats and Sri Lanka (Smith, 1943; Murthy, 1990; Maduwage, *et al.*, 2009). However, Maduwage *et al.* (2009) found no differences in specimens from the Western Ghats and from Sri Lanka. All the three species reported in Goa are Schedule IV animals and fall under the category of Lower risk- Near threatened (Molur and Walker, 1998).

Checklist of Pit Vipers found in India (Whitaker and Captain, 2004).

Sr. No	Scientific name	Name in Smith's fauna	Common name
1	*Gloydius himalayanus* (Gunther 1864)	*Ancistrodon himalayanus*	Himalayan Pit Viper
2	*Hypnale hypnale* (Merrem, 1820)	*Ancistrodon hypnale*	Indian Hump- nosed Pit
3	*Ovophis Monticola* (Gunther 1864)	*Trimeresurus monticola*	Mountain Pit Viper
	Ovophis monticola monticola (Gunther 1864)	*Trimeresurus monticola*	Western mountain Pit Viper
4	*Protobothrops jerdonii* (Gunther 1875)	*Trimeresurus jerdonii*	Jerdon's Pit Viper
	Protobothrops jerdonii jerdonii (Gunther 1875)		Jerdon's Pit Viper
5	*Protobothrops mucrosqamatus* (Cantor 1839)	*Trimeresurus mucrosqamatus*	Brown spotted Pit Viper
6	*Trimeresurus albolabris* (Grey 1842)	*Trimeresurus albolabris*	White lipped Pit Viper
7	*Trimeresurus cantori* (Blyth 1846)	*Trimeresurus cantor*	Cantor's Pit Viper
8	*Trimeresurus eryhtrurus* (Cantor 1839)	*Trimeresurus eryhtrurus*	Spot tailed Pit Viper
9	*Trimeresurus gramineus* (Shaw, 1802)	*Trimeresurus gramineus*	Bamboo Pit Viper
10	*Tropidolaemis huttoni* (Smith, 1949)		Hutton's Pit Viper
11	*Trimeresurus labialis* (Fitzinger, 1867)	*Trimeresurus labialis*	Nicobar Pit Viper
12	*Trimeresurus macrolepis* (Beddome, 1862)	*Trimeresurus macrolepis*	Large - scaled Pit Viper
13	*Trimeresurus malabaricus* (Jerdon, 1854)	*Trimeresurus malabaricus*	Malabar Pit Viper
14	*Trimeresurus medoensis* (Zhao in Zhao and Jiang 1977)	*Trimeresurus stejnageri*	Medo Pit Viper
15	*Trimeresurus popeiorum popeiorum* (Smith 1937)	*Trimeresurus popeiorum*	Pope's Pit Viper
16	*Trimeresurus andersoni* (Theobald, 1868)	*Purpureomaculatus andersoni*	Andaman Pit Viper
17	*Trimeresurus yunnanensis* (Schmidt, 1925)	*Trimeresurus stejnegeri*	Yunnan Pit Viper
18	*Trimeresurus strigatus* (Grey, 1842)	*Trimeresurus strigatus*	Horse shoe Pit Viper
19	*Trmeresurus septentrionalis* (Kramer, 1977)		Himalayan white-lipped Pit viper
20	*Trimeresurus gumprechii* (David, Vogel, Pauwets and Vidal, 2002)		Gumprecht's green Pit Viper

Ecology of Snakes

Habitat:

"The habitat of a species can be defined as that portion of a multi-dimensional hyperspace (defined by any number of habitat factors) that is occupied by a given species" (Whitaker *et al.*, 1973). Very less data relating to the interspecific niche partitioning by snakes is available as compared to other vertebrate groups (Schoener, 1977; Toft, 1985). Presently, descriptions of the preferred habitat is available only for a very few species of snakes (Reinert, 1993) and therefore, snakes are not well represented in studies of habitat selection. This may perhaps be partly due to their enigmatic nature. Few studies suggest that individual snakes actively select a suitable portion of their environment which is influenced by biotic and abiotic factors (Reinert, 1984; Weatherhead and Charland, 1985; Burger and Zappalorti, 1988; Weatherhead and Prior, 1992; Reinert, 1993). Although some species are highly specialized to exploit a narrow range of habitat, most species sporadically utilize a broader range (Heatwole, 1977). Hence, it is very important to know/ understand the probable reason for such wide variation in the habitat selection amongst the various species of snakes. Many snake species are decreasing in abundance and habitat loss is considered to be a major causal factor. Hence, for conserving a species it is important to understand a snake's distribution habitat ecology and movement patterns (Dodd, 1987; Mittermeier *et al.*, 1992; Wilson, 1992; Dodd 1993; Reinert, 1993; Losos *et al.*, 1995; Fahrig, 1997; Gibbons *et al.*, 2000; Fahrig, 2002).

The Western Ghats of south India as well, has experienced changes at a greater extent over the last century as a result of urbanization (Nair, 1991). Hence, as the pit viper species chosen for the present study have restricted distribution; their habitat destruction may lead to extinction of these species. Accordingly, it is very crucial to identify their habitat and conserve it in order to conserve these species.

Colour:

Colour changing animals are able to employ various camouflage tactics for their advantage. Crypsis is an important defensive mechanism that helps reptiles to minimize the risk of being detected by potential predators (Clark and Gillingham, 1990; Lillywhite and Henderson, 1993). This makes them perfect models for studying how crypsis is influenced by different environmental factors, such as visual background, predator and abundance, etc. Juveniles of some pit viper species attract prey with the help of their yellow tail tips, a process known as 'caudal luring' (Wharton, 1960; Carpenter and Gillingham, 1990; Gloyd and Conant; 1990). Thus, understanding the relation between different functions of animal colour patterns and their benefits is a challenge for evolutionary biologists.

Reproduction:

Studies on sexual dimorphism and courtship has been carried out in very few crotaline species, most of which are conducted in captivity (Hartmann *et al.*, 2004; Monteiro *et al.*, 2006). Thus, knowledge of reproductive behaviour has been restricted to the laboratory experiments. Sexual dimorphism in body size in association with age, reproductive competence, vulnerability to predation and competition is a common phenomenon among animals and perhaps allows the sexes to exploit different habitats (Werner and Gilliam, 1984; Janzen, 1993; Blanckenhorn, 2000; Blouin- Demers and Weatherhead, 2001a; Wikelski, 2005). Every aspect of an organism's biology is correlated with its body size, and is the most important quality of an organism (Naganuma and Roughgarden, 1990). Both the sexes of snakes display notable flexibility in their reproductive tactics. Reproduction can decrease the survival capability of females as it involves both behavioral and physiological changes (Madsen and Shine, 1993; Bonnet *et al.*, 2002). Body sizes of individual neonates are associated to the maternal body size, some taxa show significant correlations (positive or negative) between maternal and offspring sizes (Shine, 1981; Stewart, 1989). For viviparous snakes the cost of reproduction for females also extends beyond parturition and may in fact result in a high rate of mortality at post- parturition than at pre-parturition (Madsen and Shine, 1993). In snakes, low body mass is helpful for arboreal life because it enables the exploitation of a wider range of habitats. Individual neonate size is also affected by selection. Thus, morphometric measures play an important role in not only understanding the reproductive behaviour and differences in snakes but also to analyse habitat selection.

Foraging:

Optimum foraging theory is rarely mentioned in snake dietary studies. These dietary choices characterize the trophic niche of the organism and have significant allusion for ecological processes (Charnov, 1976). An individual's foraging decisions may affect its energy expenses. (Stephens and Krebs, 1986; Vitt, 1987; Arnold, 1993).

Dietary composition varies geographically (Daltry *et al.*, 1998a; De Queiroz *et al.*, 2001; Creer *et al.*, 2002), seasonally (Houston and Shine, 1993; Santos *et al.*, 2000; Hirai, 2004), between the sexes (Houston and Shine, 1993; Su *et al.*, 2005), among age groups (Cobb, 2004), within a population and amongst populations within a single species (Nakano *et al.*, 1999; Rodriguez-Robles *et al.*, 1999).

Ectothermic vertebrate populations include individuals with wide range of body sizes and thus are best examples of intra-population correlations between prey size and predator size (Arnold, 1993; Pough, 1980). Determining the food habits of a particular species is of primary significance (Litvaitis, 2000) as dietary information can help understand the relationship between prey and predator (Downes and Shine, 1998), as well as its ecology i.e foraging behaviors (Lind and Welsh, 1994), habitat use (Reinert, 1993), reproductive strategies (Shine and Madsen, 1997), migration (Forsman and Lindell, 1997) and behavioral genetics (Arnold, 1981). Data pertaining to diet is essential for wildlife management, particularly for threatened and endangered species (Litvaitis, 2000; Holycross and Mackessy, 2002).

Data on prey availability and feeding of pit vipers in different types of habitats are particularly needed, because that will help in understanding their habitat preferences and will also allow interpret their habitat suitability. This information will help in planning future species specific conservation strategies.

Behaviour:

Holistic behavioural studies in animals involve various aspects of studies as to how behaviour works (physiology), how it develops (genetic maturation and experience), its functions (social interaction and ecology) and its phylogenetic history (Ford and Burghardt, 1993). Understanding the variations in behaviour (activity patterns) is very important to know the consequences for population ecology. Most animals modify their behaviour in the presence of predators (Lima and Dill, 1990). The widely used strategy for escaping the predator is by minimizing activity during time periods when predators are most active. However, it involves several costs, such as, loss of foraging opportunities, reproduction and thermoregulation (Lima and Dill, 1990; Martin and Lopez, 1999).

Normally, snakes remain immobile for hours at a time and move only at nightfall (Sun *et al.*, 1990). Snakes lying in wait for prey espouse unique postures (Shine and Sun, 2002). Behavioural traits are often influenced by the environment and over lifetime of an individual. The behavioural and physiological processes of reptiles are temperature dependent (Huey, 1982) which may affect their activity patterns and these differences in turn may influence species fitness. Humidity was also shown to influence snakes behaviour (Daltry *et al.*, 1998 b). Knowing the activity levels enables the researchers to predict the most favorable time for collecting and observing the species, which might help to understand the counts of animals to estimable population size (Gibbs, 2000; Sun *et al.*, 2000).

PIT (Passive Integrated Transponder) Tagging:

Long term demographic studies of animals under natural conditions often require that the study organisms are marked individually using a technique that does not affect the survival, activities or performances of an individual. Such techniques help to determine the growth rate, movement pattern, population size and other features that are essential to understand the population ecology (Fitch, 1987). Although a variety of techniques have been developed to mark animals, only a few selected techniques are being used on snakes. Most field studies of habitat use in snakes have relied on radiotelemetry, which allows for a comprehensive study of larger individuals. However, this technique usually prohibits studies of ontogenetic shifts in habitat use since transmitters historically have been too large to implant within neonates and juveniles of most species. Of late small microchips called PIT tags are used to mark snakes (Jemison *et al.*, 1995). Use of "PIT tags" is one of the biggest breakthrough in the identification of Wildlife. PIT tagging has been also used in U.S. Ecological laboratories on fish and turtles. SERL (Savannah River Ecology Laboratory) is among the first laboratories to use PIT tags on snakes. PIT tag consists of a wire-wound glass-encapsulated chip, about the size of a grain of rice laid end to end. This is used to mark the individuals and helps in identifying the individuals in captivity as well as in the field. PIT tagging studies help us to know the movement pattern of the snakes. Patterns of animal movement can provide useful information on their migration, dispersal, homing activities, activity area and site selection for reproduction.

Phylogenetic studies

While it has for long been accepted that pit vipers evolved in the Old World and invaded the New World across the Bering Land Bridge, other aspects of the relationship between Old and New World pit vipers have been more contentious. An early division of Asian pit vipers into the *Trimeresurus* and *Hypnale* groups, based largely on osteology, led to the view that each of these groups had invaded the New World independently (Malhotra *et al.*, 2010). Despite intense recent research interest in viperid phylogeny, the evolutionary relationships between the major pit vipers species remain inadequately understood due to a lack of a comprehensive analysis of the entire family. The phylogenetic studies in the family *Viperidae* especially pit vipers hold great potential in identifying genetic structure, ancient and recent dispersal and sympatry of cryptic species using mitochondrial genes sampled across the entire family. There has been subsequent effort towards resolving an accurate molecular phylogenetic tree for all pit vipers, which has involved increasing taxon sampling and number of characters included, as well as use of increasingly more sophisticated models of sequence evolution and methods of analysis (Malhotra and Thorpe, 2004a; Castoe and Parkinson, 2006). However, there are still attempts required to revise the phylogeny of Western Ghats pit viper. Based upon recent report (Malhotra *et al.*, 2010), an attempt is made in the present study to analyse the phylogenetic resolution of three species of Western Ghats pit vipers in relation to New World pit viper, Indo-Malayan pit viper and Indian sub-continental pit vipers groups and to understand their radiation pattern during the course of evolution.

Threats and Conservation

Not many scientific reports are available regarding the conservation strategies of snakes, although many NGO's are involved in this activity. Direct killing of snakes has tended to attract more attention from community-based "conservation" organisations than from professional scientists. Predation is also a significant source of mortality for many species of animals (Vermeij, 1982; Endler, 1986). Many animals respond to people as potential predators and tend to avoid humans which may result in displacement from their home range (McLellan and Shackleton, 1988), disruption of foraging (Gander and Ingold, 1997) and reduced reproductive success (Safina and Burger, 1983; Giese, 1996).

Transport networks including National highways and central railway lines pass through many of the protected areas resulting in increased threats on the wildlife of these areas. Local tribes often collect leaf litter, chop off branches / twigs (almost rendering the tree devoid of any crown) for domestic use. Often huge amounts of leaf litter are collected resulting in considerable decreases of humus and changes the chemical composition of the soil thus, indirectly affects the microhabitat of many organisms. Shifting cultivation, involves the clearing and denuding of small patches of forest for cultivation. This type of practice in protected areas directly affects habitat, resulting in its fragmentation and degradation. Factors such as felling of tress, grazing by domestic cattle, forest fire and collection of minor forest products like tubers, bulbs and herbs increase soil erosions. Reptiles might be more vulnerable to human disturbance in such instances because of their limited mobility and restricting movement to less disturbed areas. However, species with high habitat specificity and small ranges may not be able to emigrate successfully and local extinction may thus be tantamount to species extinction.

Parks and nature reserves protect important natural habitats but also provide public opportunities for outdoor recreational activities that may have unintentional negative effects on wildlife. All these impacts may influence the continued viability of populations and thus, have attracted increasing study from conservation biologists (Alexander and Waters, 2000; Jones, 2000; Lode, 2000). The entire stretch of Western Ghats in Goa is protected, but the impact of increasing visitors to these parks on snake populations is unknown.

Study Species

Snakes play a very important role in ecosystem, because of their middle position in many food webs. However, reliable data on snake population is rare due to the difficulty in sampling these patchily distributed, cryptic and mostly nocturnal species and also due to their under representation in the ecological literature (Lind *et al.*, 2005). These animals typically exhibit frequent periods of prolonged activity (Pough, 1980). Further, their ectothermy allows a wide range of body sizes of ecologically independent individuals within a population (Pough, 1980; Shine *et al.*, 1998).

Pit vipers can be relatively easily captured using visual encounter survey because of their ambush predation habit. The three species found in Goa differ in their habit, *T. malabaricus* and *T. gramineus* are arboreal in nature, whereas, *H. hypnale* is terrestrial

(Smith, 1943; Murthy, 1990; Whitaker and Captain, 2004; Khaire, 2006; Pradhan, 2008). The presence of facial pits, allows them to detect modest temperature fluctuations in their environment. It was previously thought that these organs were used solely to aid in prey acquisition, but recent findings (Krochmal and Bakken, 2003) demonstrated that this organ is also used to direct behavioral thermoregulation. These organs respond to thermal radiation and thus allow the snake to detect environmental temperatures from a distance (Bullock and Diecke, 1956; Bullock and Fox, 1957; De Cock Buning, 1983; Bakken and Krochmal, 2007). Krochmal *et al.* (2004) reported that the ability to use thermal radiation to direct thermoregulatory behavior is present in all pit viper taxa they studied.

Several studies on pit vipers have focused on their phylogeny (Krochmal *et al.*, 2004; Sanders *et al.*, 2004; Castoe and Parkinson, 2006). Very few reports are available on phylogenetic studies of Indian pit vipers involving a very small sample size (Malhotra and Thorpe, 2000; Giannasi *et al.*, 2001; Creer *et al.*, 2003; Malhotra and Thorpe, 2004a; 2004b; Creer *et al.* 2006). Limited number of reports are available on pit vipers at a global level on their habitat ecology (Tu *et al.*, 2000; Oliveira and Martins, 2001; Shine *et al.* 2002a; 2002b; 2002c; Valdujo *et al.*, 2002; Lin *et al.*, 2007; Eskew *et al.*, 2009), foraging ecology (Secor and Nagy, 1994; Daltry *et al.*, 1998a; Creer *et al.*, 2002, Shine *et al.*, 2002a; shine and Sun, 2003, Monteiro *et al.*, 2006; Tsai, 2007; Lin and Tu, 2008; Vincent and Mori, 2008; Eskew *et al.*, 2009;), distribution (Huang *et al.*, 2007), reproduction and morphology (York, 1984; Hartmann *et al.*, 2004; Monteiro *et al.*, 2006), taxonomy and evolution (Martins *et al.*, 2001; Marques *et al.*, 2002; Luiselli, 2006; Lillywhite *et al.*,

2008) and behaviour (Daltry *et al.*, 1998b; Oliveira and Martins, 2001; Sun *et al.*, 2000; Roth and Johnson, 2004).

Only a limited number of ecological studies (Murthy, 1990; Daniel, 2002; Whitaker and Captain, 2004 and Khaire, 2006) have been carried out in India which have focused on their diversity and distribution. Thus, studies on the ecology, distribution and abundance of Indian pit vipers are very rare, with special reference to Goa region. Diverse habitats of Goan pit vipers (*T. malabaricus* is endemic to Western Ghats, *T. gramineus* to the peninsular India and *H. hypnale* is restricted to Western Ghats) makes it very important to know their ecology in order to conserve these species. Very limited information is available on the ecology of these snakes and the studies of their spatial ecology have never been conducted. Hence, present study was aimed to know the habitat of these species, seasonal variation in habitat use, to identify the threats and device strategies for the conservation of its habitat and population.

Literature Review

Most of the studies on ecology and phylogeny of pit vipers are restricted to the pit viper species inhabiting outside the Indian subcontinent. York (1984) was the first to report the combat ritual in Malayan pit viper (*Calloselasma rhodostoma*), an Old World pit viper. The feeding ecology of *C. rhodostoma* in South-east Asia was studied by Daltry *et al.* (1998a) and they reported ontogenetic and intraspecific variation in its diet. Daltry *et al.* (1998b) further examined the impact of environmental factors on *C. rhodostoma* and revealed that ambient humidity influences the activity pattern of this pit viper species.

Tsai and Tu (2000) studied the reproductive cycle of male Chinese green tree vipers, *Trimeresurus s. stejnegeri,* in northern Taiwan by examining seasonal changes in the morphology and histology of their reproductive organs and reported hypertrophy of the renal sexual segment of *T. s. stejnegeri* that occurred from late summer to winter and related it to mating activities observed in the same period. Tu *et al.* (2000) analyzed habitat selection between male and female *T. s. stejnegeri* and found no difference in habitat selection between females and males. Martins *et al.* (2001) investigated the relationships of body size and form (tail length and stoutness) with macrohabitat use in 20 forms of *Bothrops* in all main ecosystems of Cis-Andean South America and they reported semi-arboreal habits in forest forms. Their findings indicated that tail size, stoutness and body size may be affected by selective agents other than macrohabitat use and the macrohabitat use, morphology and body size might be the key features that helped in the highly successful ecological diversification of *Bothrops* in South America. Oliveira and Martins (2001) described activity and habitat use in *Bothrops atrox* from central Amazonia and reported that *B. atrox* is significantly less active during the dry season and their monthly number found correlated with rainfall and relative humidity, but not with temperature. They also reported ontogenetic shift in microhabitat use by *B. atrox* and related it to food availability and higher predation pressure. Sun *et al.* (2000) studied the influence of biotic (age, sex and local conditions) and abiotic (seasons, temperature, relative humidity and wind speed) factors on activity patterns of pit viper (*Gloydius shedaoensis),* their analysis suggested that the weather conditions (temperature and humidity) during field surveys influences the number of snakes encountered during the survey.

The reproductive cycle of 132 female Chinese green tree vipers, *T. s. stejnegeri*, in northern Taiwan was studied by Tsai and Tu (2001), they examined seasonal changes in their hormone levels and reproductive organ morphology and histology. Their results suggest that female Chinese green tree vipers exhibited low-frequency reproduction, postnuptial vitellogenesis, and long-term sperm storage. Creer *et al.* (2002) determined dietary data for 229 *T. stejnegeri* from Mainland and Offshore Island (Taiwan) and found no variation in diet composition between sexes but reported variation in diet within same species as a result of geographic variation and attributed this to the difference in prey availability. Marques *et al.* (2002) described a new pit viper species, *B. alcatraz* of the *B. jararaca* group from Alcatrazes Island, Brazil. Shine *et al.* (2002a) examined whether thermal factors influence foraging-site selection by *G. shedaoensis* and reported that thermal factors modify the suitability of alternative ambush locations for these pit-vipers. Shine *et al.* (2002b) further studied consequences of habitat selection between adults and juveniles of *G. shedaoensis* and reported ontogenic shift in habitat selection as a result of ontogenetic shifts in the viper's ability to capture and ingest large, mobile prey. A review of 30 years of ecological research on Shedao pit viper that stimulated major conservation initiatives which increased the number of pit vipers substantially and shifted the age structure of the population was provided by Shine *et al.* (2002c).

Valdujo *et al.* (2002) provided ecological information on *B. neuwiedi pauloensis,* an endemic species to Brazilian Cerrado regarding geographical distribution, habitat use, biometry, feeding habits, and reproduction, based on field studies and analysis of 175 preserved specimens. Shine and Sun (2003) analyzed attack strategy of an ambush predator, Shedao pit viper (*G. shedaoensis*) on a small island in north-eastern China, to know as to why larger predators consume larger prey. Their result indicated that the ontogenic shift in diet is a result of combination of various processes such as gape-limitation, active refusal to strike at small prey and to terrestrial rather than arboreal ambush sites. Wang *et al.* (2003) collected litters of neonates of *T. s. stejnegeri*, at Tsaochiao, Taiwan a viviparous snake to examine skewed sex ratio and determine the causes of numerical dominance of males in the adult sample and attributed this to differential mortalities between sexes that are probably derived from a higher cost of reproduction in females.

Hartmann *et al.* (2004) provided information on the reproductive biology of captive individuals of *B. n. pubescens*. Variation in antipredator behaviour within a cottonmouth (*Agkistrodon piscivorus leucostoma*) population was examined by Roth and Johnson (2004), they reported the defensive response to decline with increase in body size. Luiselli (2006) reviewed and analyzed the peer-reviewed snake diet literature available to explore whether there are broad patterns in the interpopulation variability of diet composition in populations belonging to 58 species of snakes from some of the main families (1 Boidae, 2 Pythonidae, 27 Colubridae, 10 Elapidae, and 18 Viperidae). The study revealed that, within-species snake populations showed a very low variability in terms of diet composition and sit-and-wait strategy was associated essentially with species of the family Viperidae. Monteiro *et al.* (2006) gathered information on diet, reproduction, and morphology for *B. mattogrossensis* using museum specimens, no ontogenetic shift in diet from ectothermic to endothermic prey observed in *B. mattogrossensis* as in other species of *Bothrops*. Reproduction was reported to be seasonal, with a vitellogenic period concentrated at the end of the dry season. Sexual dimorphism in body size was also reported.

Huang *et al.* (2007) measured and compared the acute thermal tolerances of a high-altitude pit viper, *T. gracilis*, with that of its lowland congeners, *T. mucrosquamatus* and *T. s. stejnegeri*, to test whether their thermal tolerances are limiting factors determining their altitudinal distributions. They did not find a clear relationship between acute thermal tolerances and altitudinal distributions of these three *Trimeresurus* species. Lin *et al.* (2007) examined the role of vegetation cover, prey availability, and air temperature on the selection of a retreat site by the *T. s. stejnegeri*, they manipulated the vegetation structure and distance to the prey source, and monitored the microhabitat temperature within the test enclosures. Their results indicated that temperature influences the retreat site selection by the snake. Tsai (2007) studied the prey handling behaviour in *T. s. stejnegeri* in the laboratory and in most cases, the snake gradually moved its jaw to the higher end of the prey and began ingesting it, as an adaptation for arboreal feeding.

Lillywhite *et al.* (2008) reported invasion of terrestrial vertebrates to the sea giving an example of Florida cottonmouth pit viper (*Agkistrodon piscivorus conanti*) that inhabit the Gulf coast islands. Lin and Tu (2008) verified the gut contents and conducted feeding trials to study the food habits of the *T. gracilis*, they reported that prey mass was positively correlated with snake snout-vent length and observed an ontogenetic diet shift from ectothermic to endothermic prey, whereas adult females and males presented different diets. Vincent and Mori (2008) examined the relationship amongst a number of functionally important variables and the predatory behaviour of free-ranging pit vipers (*Ovophis okinavensis*) from Okinava Island, Japan. They reported temperature to influence the feeding performance of this snake.

Eskew *et al.* (2009) characterized the foraging strategy and microhabitat use of Eastern cottonmouth (*A. piscivorus*) a semi aquatic pit viper at Ellenton Bay. Cottonmouths exhibited an ontogenetic shift in foraging strategy and microhabitat selection in juveniles and adults. Maduwage *et al.* (2009) carried out a taxonomic revision of the South –Asian Hump-nosed pit vipers (*H. hypnale*) and found no difference between the *H. hypnale* from Sri Lanka and India. The differences in habitat selection, daily activity and preferred ambient temperatures between adult and neonate Halys pit-

Krochmal *et al.* (2004) conducted phylogenetic survey of viperine thermoregulatory behaviour cued by thermal radiation to assess the role of facial pits in behaviour of pit vipers suggest that thermoregulatory behavior cued by thermal radiation is a universal role of facial pits and probably represents an ancestral trait among pit vipers. Malhotra and Thorpe (2004 a) carried out a systematic revision of a cryptic green pit viper complex (*T. stejnegeri*) using a combined molecular and morphological analysis. They (Malhotra and Thorpe, 2004c) also reported *T. venustus* to be a separate species from *T. kanburiensis* based on the multivariate morphometric analysis. Sanders *et al.* (2004) analyzed molecular and phenotypic evolution in a group of Indomalayan pit vipers, the *T. sumatranus* group using mitochondrial DNA sequencing and reported distinct interspecific divisions within the group. Castoe and Parkinson (2006) carried out extensive sampling of taxa and sequences of four mitochondrial gene fragments to estimate the phylogeny of pit vipers based on maximum parsimony and Bayesian phylogenetic methods, their results of pit viper phylogeny suggests that nearly all generic reallocations of pit viper species (New World and Old World genera) were valid.

Objectives

1. The habitat ecology and habitat preference in pit vipers.
2. Colour variations in pit vipers.
3. Reproduction in pit vipers.
4. Foraging ecology of pit vipers.
5. Behavior of pit vipers.
6. Pit tagging.
7. Tracing systematic phylogenetic relationship of pit vipers found in Goa.
8. Identification of threats.
9. Suggest measures for conservation of pit vipers.

CHAPTER 2

METHODOLOGY

Description of study Area

Goa (3,702 sq. km) is the smallest state of the Indian union. It is situated on the Malabar Coast and is bounded by Karnataka on the east and south, Maharashtra on the north and the Arabian Sea on the west. The State of Goa is located between 14°53'54" to 15°48' N latitude and 73°40'33" to 74°20'13" E longitude. The entire Goa state can be divided into three main physiographic units viz, the mountainous region of the Sahyadri in the east, the middle level plateaus in the centre and the low-lying river basins with coastal plains (Rao, 1985-86). Goa includes a portion of the Western Ghats, a range of mountains 1,600 km long extending from north of Mumbai to Cape of Comorin (Kanyakumari), which is identified as one of the 'hotspots' of biological diversity and endemism in the world (Myer, 1990; Myer *et al.*, 2000). The Ghats extend in the north south direction, and exhibit rise in altitude. Goa has a hilly terrain especially on its eastern side where lies the southern end of the northern part of the Western Ghats.

Climate:

The State of Goa is situated in the tropics and has profound orographic influence. The climate is humid throughout the year, with humidity level ranging from 75% to 95% in the monsoon. The main feature of the Goan climate is the south-west monsoon, which occurs between June and September. The average rainfall is 2500 mm to 3000 mm, although in Western Ghats the downpour is considerably high (over 4000 mm) than on the coast. In addition there are pre-monsoon (May) and post-monsoon (October) showers as a result of the north-east monsoon. Goa receives rain from the south-west monsoon, thereby experiencing a dry period lasting from November to May [November to February (winter) and March to May (summer)]. There is a slight variation in temperature through the seasons. May is the relatively warmest month and the mean daily temperature is around 30° C and maximum temperature rises to 36° C. January is the coolest with mean daily temperature of about 25° C. The average temperature ranges between 21° C and 30° C (Joshi and Janarthanam, 2004).

Forest:

Thirty five percent of the area of Goa is under forest cover and originates from Archaen rock. Forests are confined to the Western Ghat foothill slopes mainly in the Talukas of Sanguem, Sattari, Cancona and Quepem and to a lesser extent in the Talukas of Ponda, Pernem and Bicholim. Tropical forests classification developed for greater India by Champion (1936) was widely accepted and the same was revised and republished for present-day India by Champion and Seth (1968). This approach has proved to have wide global application. As per Champion and Seth (1968), 16 major forests types are recognized in India and these are further subdivided into 221 minor types based on their structure, physiognomy and floristic features. The major forest types of Goa can be categorized into west coast tropical evergreen, west coast semi-evergreen, southern moist deciduous forest and southern secondary moist mixed deciduous forest. The sub-types include cane brakes, wet bamboo brakes, moist bamboo brakes, lateritic semi-evergreen forest, slightly moist teak forest, south Indian sub-tropical hill savannah woodland and southern sub- tropical hill forest, lateritic scrub and dry tropical river rain forest. The moist deciduous forest is the most dominant habitat, compared with the evergreen and semi-evergreen forests, which are restricted to a few patches at higher elevation and along streams.

Western Ghats:

Goa occupies about 2% area of Western Ghats (Joshi and Janarthanam, 2004). Western Ghats are very rich in wildlife and endemic species (Gadgil and Guha, 1992). Biodiversity of Western Ghats is under threat due to deforestation (Myer, 1990; Menon and Bawa, 1997; Jha *et al.*, 2000). Amongst the 530 species of reptiles presently reported from India, 260 species are reported from the Western Ghats of which 98 are endemic (Daniel, 2002). Many reptiles in the Western Ghats have restricted distribution, which is a major reason for many of them (63 Species) being threatened (Kumar *et al.*, 1998). In spite of high endemism and threat, there are only a few studies on the habitat preferences and community structure of reptiles in the Western Ghats (Inger *et al.*, 1987; Bhupathy and Kannan, 1997). Herpetofauna has received poor attention in India and has not been studied in detail (Vasudevan *et al.*, 2001) and it is possible that a few species have already been lost even before being reported (Dar *et al.*, 2008).

Study Sites:

The field work was conducted in five protected areas of Goa, viz. Mhadei Wildlife Sanctuary, Bhagwan Mahaveer Wildlife Sanctuary and National Park, Bondla Wildlife Sanctuary, Netravali Wildlife Sanctuary and Cotigao Wildlife Sanctuary. The study sites are represented in the map in figure: 1. the forest types present in each of the study site is represented in table 1.

Mhadei Wildlife Sanctuary (MWS):

This Sanctuary is located in Sattari Taluka and has an area of about 208.48 sq.km. It covers the northern extremity of the Western Ghats in Goa and is situated between 15° 27'30'' N to 15° 41'0'' N latitude and 74°5'0'' E to 74° 16'0'' E longitude. It is bounded towards north by Maharashtra- Karnataka State border, on the eastern side by Karnataka State boundary, towards south by Bhagwan Mahaveer Wildlife Sanctuary and on the western side by the villages of Gavanem, Assodem, Sirsodem, Sirangulim, Caranzal, Mhadei river, Carambolim Brahma, Sigonem, Codal, Golauli, Ivrem Curdo, Ivrem Buzruco, Chhoraundem, Pale, Copordem, Dabem, Zorme, Gullulem and Quelaudem of Goa State.

The terrain is hilly towards north and north-east in a semi-circular shape. The Sanctuary has three highest hill peaks of the state viz, Sonsogad (1,027 m), Talavche Sodo (812 m) near Satrem village and Vagheri (named after tiger) is 725 m high. In the east and south Mhadei Sanctuary forms a traditional corridor for the movement of wild animals from Anshi - Dandeli (Karnataka). Typical tropical climate prevails in Mhadei Wildlife Sanctuary with an average annual precipitation of 3750 mm. Of late monsoon is quite erratic. Temperature varies from 23 to 35° C.

Bhagwan Mahaveer Wildlife Sanctuary and National Park (BMWS):

This Sanctuary and national park are located in Sanguem Taluka and has a total area of about 240 sq. km. and extends between 15° 19' 48" N to 15° 29' 27' N latitude and 74° 9' 26' E to 74° 20' 12" E longitude whereas, the NP extends between 15° 15' 30" N To 15° 25' N latitude and 74° 13' 46" E to 74° 20' 12" E longitude. It extends from the highest ridges of the Western Ghats in Goa to its foothills. It lies along the eastern part of Goa and its eastern boundary is adjacent to Dandeli Sanctuary in Karnataka. The northern part and the southern part bound by MWS and NWS respectively. The NP lies along the eastern border of Goa, partly on the plains and partly on the western slopes of the Western Ghats. It is located in the central part of the BMWS and in fact bisects the Sanctuary into a northern portion and a south – western portion. Hence, the terrain, climate, flora and fauna of both these regions are almost identical. The terrain is typically that of the sahyadri range, from gently undulating hills to very steep mountains. The altitude ranges from 22 to 891 m and the temperature ranges between 28.9 to 32.8° C. Humidity ranges from 50% to 96% and receives mean annual rainfall of 3,556 mm.

Bondla Wildlife Sanctuary (BWS):

It is located at the junction of the three Talukas – Ponda, Sattari and Sanguem covering the villages of Usgao and Ganjem of Ponda Taluka. Darbandora and Pillien of Sanguem and Conqurin of Sattari Taluka. It has an area of 7.95 sq. km. The Sanctuary is located at a latitudinal range of 15° 24' 39" N to 15° 26' 55" N and longitudinal range of 74° 05' 28" E to 74° 07' 21" E. It lies within the bio-geographic province of the Western

Ghat Mountain with hilly terrain. Fifteen percent of the Sanctuary is kept for the visitors. There is a tourism zone which includes garden, zoo, deer safari for the tourist complex. All these areas are located roughly in the centre of the Sanctuary. The altitudinal range is between 60 to 461 m, temperature ranges between 25 to 33° C. The average annual rainfall varies from 4,232 to 6,240 mm, humidity is high going up to 96% at times.

Netravali Wildlife Sanctuary (NWS):

This Sanctuary is located in Sanguem Taluka and has an area of about 211.05 sq.km. and is situated between 14 "N to 15°7'17N latitude and 74°5'0'' E to 74° 16'0'' E longitude. The Sanctuary forms the link between the Bhagwan Mahavir Wildlife Sanctuary in the north and the Cotigao Wildlife Sanctuary located to the south in Canacona Taluka. In terms of the geographical location, the Netravali Wildlife Sanctuary is in south Sanguem Taluka along the eastern side of Goa. Netravali Wildlife Sanctuary is the largest Sanctuary in Goa. It shares eastern state boundary of Goa with Karnataka, The southern boundary of Bhagwan Mahavir Wildlife Sanctuary, southern boundary: northern boundary of Cotigao Wildlife Sanctuary, western boundary: runs along the villages of Mangal, Neturli/ Netravali, Portem, Curdi, Salauli, Tudov, Patiem further joining southern boundary of Bharwaan Mahavir WildlifeSanctuary. Highest elevation in the Sanctuary goes up to 862 m. This point is known as Ravan Dongor and is present on the border of Netravali and Cotigao. Major part of the Sanctuary has semi evergreen, evergreen to moist deciduous forest. Temperature ranges between 22 to 32° C and the humidity ranges between 60 to 97%. The mean annual rainfall is about 3,500 mm.

Cotigao Wildlife Sanctuary (CWS):

This Sanctuary is located in Canacona Taluka and lies along the south eastern border of Goa. The total area of the Cotigao Wildlife Sanctuary is 85.65 Sq Km. It is located at a latitudinal range between 14° 55' 30" N to 15° 2' 9" N and latitudinal range between 74° 6' 54" E to 74° 15' 54" E. It is bounded by state of Karnataka on eastern side, on northern side by Netravalli Wildlife Sanctuary, western side by Gaodongrim village and on southern side by Poinguinim village. The Cotigao Wildlife Sanctuary has undulating terrain with hill ranges extending from north to south, it lies at an altitudinal range of 10 to 843m, the highest point (843m) commonly referred to as "Ravana Dongar". The temperature ranges between 22 to 32° C, it receives a mean annual rainfall of about 3,000 mm. The maximum humidity attained is up to 96 %.

Survey and sampling methods

The present study was conducted (from June 2005 to May 2009) in Mhadei Wildlife Sanctuary (MWS: 208. 48km^2), Bhagwan Mahaveer Wildlife Sanctuary and National Park (BMWS: 241km^2), Bondla Wildlife Sanctuary (BWS: 8km^2), Netravali Wildlife Sanctuary (NWS: 211.05km^2), Cotigao Wildlife Sanctuary (CWS: 86 km^2) and in cashew (*Anacardium occidentale*) plantations within and adjoining areas of these protected areas. Altitude of the study areas ranged from 20 to 800 m. Details of the transects laid down for the study are provided in table 2a-e.

The distribution, diversity and abundance of pit vipers were studied in all protected areas mentioned above using band transect methodology of Dahanukar and Padhey (2005). Surveys were carried out on foot in different seasons (summer - March to May, monsoon - June to October and winter - November to February). Surveys were conducted during day and night in predetermined transects (Band transect), each of 2500 x 20 m size were selected randomly before the onset of the study and sampling was carried out in these transects only. All the individuals encountered on these transects were identified to the species level Smith (1943), Murthy (1990) and Daniel (2002) and the number of individuals was recorded. As and when the pit vipers were encountered the geographical position, altitude and location were recorded using a handheld Geographical Positioning System (GPS). Further, the relative humidity and ambient temperature of the site where the pit viper was encountered were recorded using a hygrometer and mercury thermometer respectively.

Transects were traversed once in a month at each study site by the researcher with the help of local volunteers. Each transect was precisely examined for four hours and search was performed both at day and night. Searching activities were performed in cashew plantations during the weed clearance and in protected areas during fire tracing and clearance of view line. The survey consisted of 2-4 people moving slowly along the transect, turning logs and stones, ripping apart rotten wood, moving floor debris (leaf litter), inspecting the herb and shrub layer up to about 10 m for arboreal species and riparian zones. Further all the relevant microhabitat prevalent in the transects were also surveyed thoroughly by these observers.

Snakes were collected by hand or using snake stick throughout the field season. All the encountered snakes were classified either as juveniles (<150 mm SVL) or adult (> 150 mm SVL). Captured snakes were released at their respective captured spot and to avoid recapturing the same snake it was marked by clipping a ventral scale. (Spellerberg, 1977).

Data Analysis:

Species abundance was calculated from the actual number of individuals encountered in the band transect during transect sampling. The variance for the abundance of each species with respect to 4 years and also the variance for the abundance of each species with respect to 5 study sites were tested using one-way ANOVA. Further, the variance of abundance of each study site with respect to three species was also analysed using one-way ANOVA.

The variance in distribution of each species (*T. malabaricus, T. gramineus and H. hypnale*) with respect to different altitudinal range (20-100 m, 101-200 m, 201-300 m, 301-400 m, 401-500 m, 501-600 m, 601-700 m and 701-800 m) was tested using the two-way ANOVA to know whether altitude gradient influence the distribution of these species. The mean abundance of the three species in each of the study site and across seasons (summer, monsoon and winter) was also tested to know whether the seasonal variation in each study site had any influence on abundance of the species using two-way ANOVA.

Habitat Assessment

The habitat selection by pit vipers was examined at three spatial scales. Difference, if any, in the habitat composition within each snake's home range from habitat composition within the total study area was determined.

The snake's locations within its home range was distributed among the habitat types in proportion to the amount of each habitat in their home range was determined.

Finally, seasonal shifts, if any, in selection of features within habitats was examined by comparing microhabitat variables between winter and active season snake-selected sites.

Habitat selection separately by sex and by season was also examined. The forest types was classified based on Champion and Seth (1968) and the forest types preferred by each species of pit viper and also the habitat types present in each study area was analyzed.

Macrohabitat Assessment:

The macro-habitat was classified as forest, forest edge or open habitat. Further, forest edge was defined as any location, 15 m from where forest met open habitat (e.g., fields and rocky outcrop) (Blouin-Demers and Weatherhead, 2001a). To determine microhabitat selection, a variety of features at every other snake location was measured. For arboreal species, whether or not it was in a tree, the tree species, its height of perch, position on the branch (distal/apical), diameter of the branch , the tree canopy (thick/ sparse) and vegetation of the area (thick / sparse) was recorded. For terrestrial species the leaf litter thickness, status of the ground (bare/leaf litter) if on bare ground, whether the snake was closer to cover objects (retreat site) was recorded. Seasonal shifts in habitat use are a consistent feature of the ecology of many snake species (Reinert, 1993) as well as other types of reptiles (Paulissen, 1988). Activity cycles also appear to be seasonal among diverse animal taxa in the tropics. Thus, assessment of habitat was done to know how patterns of habitat use vary seasonally; hence, the analysis also involves seasonal comparisons of snake-selected sites.

Microhabitat Assessment:

Whenever a snake was sighted all the hygrothermal profile of the habitat, for terrestrial species the ambient and the leaf litter temperature and humidity was recorded whereas for arboreal species shaded ambient (air) temperatures and humidity was recorded following the methodology of Shine *et al.* (2005) with few modifications. The shaded temperature and humidity at different heights above the ground (using an electronic thermometer) were recorded. The temperature was recorded on the ground up to the point where the snake was located with a distance of 300 mm between two readings and the height was retained up to 600 mm above the point where the snake was located. This data helps to show the consistent association between thermal regimes and snake locations.

Data Analysis:

The variance in habitat use (forest, forest edge and open) by each species, the variance in preference of habitat type by each sex (male and female) of each species separately, the preference of *H. hypnale* for forest area and cashew plantation separately with respect to different seasons was tested using One-way ANOVA. The variance in abundance of the gravid and non-gravid females of *H. hypnale* in forest and cashew plantation was analyzed using the two-way ANOVA.

The variance in utilization of tree species by the two arboreal species (*T. malabaricus* and *T. gramineus*) and by males and females of *T. malabaricus* and *T. gramineus* was tested separately using the one-way ANOVA. The same was also used to test the variance in perch height attained by males and females of *T. malabaricus* and *T. gramineus*. Two-way ANOVA was used to test the variation in perch height attained by *T. malabaricus* and *T. gramineus* during different seasons.

The variance in perch height attained by the arboreal species and the variation in perch diameter used by males and females of *T. malabaricus* and *T. gramineus* separately was tested using One-way ANOVA. The same was also used to test the difference between the ambient and leaf litter temperature and humidity in forest and cashew plantations.

The correlation between perch height and body length of males and females and for perch diameter and body mass of males and females of *T. malabaricus* and *T. gramineus* separately was also analyzed. The difference in the utilization of branch position (apical, distal and middle) by each species (*T. malabaricus* and *T. gramineus*) of arboreal pit viper was tested using Two-way ANOVA.

Colour

The colour change exhibited in all the three species during different seasons and whether the change in colour is influenced by substrate used or climatic conditions was assessed during the present study. The colour difference in sexes to know if sexual dimorphism in colour exists in pit vipers studied was also analyzed.

Reproduction Study

Reproductive study on all the three species was carried out mainly based on field observation. The breeding seasons were identified based on the field observations such as locating the snakes in copulation as well as their behaviour. After capturing the snake it was inserted in a transparent plastic pipe and morphometric data such as snout-vent length (SVL), total length (TL), caudal length(CL), head length (HDL),head width (HD W), ventral scales(VS), caudal scales(CS), and body mass in grams (using electronic balance) was recorded (Plate:1). The sex, sexual dimorphism and maturity were determined based on the scale count and morphometric data (Keogh *et al.*, 2000).

Reproductive condition of females was assessed by palpitation of the abdomen periodically throughout the field season.

The gravid females encountered from Jan 2009 to Dec 2009 were collected and kept in captivity. A gravid female of *H. hypnale* was collected on 19th January 2009 and another gravid female on 6th April 2009 from MWS (Kumthal) in the cashew plantation. The gravid females of *H. hypnale* were housed individually till the time of parturition in a glass tank (670 x 365 x 457 mm). The enclosure contained natural vegetation and cover (logs, leaf litter, and gravels), that provided snakes access to direct sun or shade. To keep the temperature cool, water was sprayed on leaf litter. Temperature in the tank room fluctuated with ambient temperatures (30 to 32 °C). The females were kept for basking for half an hour every day. Snake was fed with small frogs, skinks and house lizard once a week and the tank was also provided with a bowl of water (Weatherhead *et al.*, 2006). The exact gestation period was not recorded but the number of days from the date of capture till parturition occurred were counted. After parturition the litter size and number of mortalities were recorded and the neonates were collected. Within 24 hours of birth data pertaining to the morphology of each neonate was procured. The females along with the neonates were released at the point from where it was captured 24 hours after parturition. Data regarding number of fertilized eggs was collected from two gravid females which were killed by the locals in the cashew plantation.

Data Analysis:

The variation in SVL, CL, HDL, HDW, VS, CS and body mass of males and females of all the three species were tested separately using the one-way ANOVA, the same was also used to test the difference between SVL, CL, HDL, HDW, VS, CS and body mass separately for all the three species. The correlation between body mass and total length of males and females was also tested for each species separately. Correlation was also tested between body length of gravid females and their litter size. The variation in SVL, CL, HDL and HDW of male and female neonates of *H. hypnale* were tested using the one-way ANOVA.

Foraging

Present foraging studies of pit vipers were based on laboratory experiments. The prey for both terrestrial and arboreal species was identified based on field observations. Prey items were identified upto the species level and recorded. Retreat site and foraging sites were analyzed to know whether the pit vipers utilized their retreat sites as foraging sites during different seasons. Prey preference studies were undertaken in captivity for adults (all three species), as well as gravid pit vipers (*H. hypnale*), using live prey items such as frogs, skinks, calotes, house lizards and rodents.

Index of prey availability:

Monthly sampling of the available prey (frogs, skinks and other agamids) was studied in CWS (DA, BR, TTA and HA) from November 2007 to October 2008 for *H.*

hypnale, and species wise prey availability was quantified employing adaptive cluster sampling technique of Ishwar *et al.* (2001). The basic sampling unit was 5 m × 5 m randomly laid quadrats. The number of primary quadrats were kept constant (13) for all the seasons. If a prey species was sighted in any of these primary quadrats, secondary quadrats of the same dimension with one meter gap between the primary and secondary quadrats were laid on all four sides of the primary quadrats and searched for prey. If any of these quadrats had the prey species, further quadrats were laid around them until the quadrats with prey were bounded or surrounded by quadrats without any prey species. The group of primary quadrats with the prey then becomes a single cluster. If the primary quadrat did not have any prey, the sampling was carried out in the next randomly selected primary quadrat. To minimize the chances of missing prey during search, two observers searched the quadrat from opposite sides towards the centre of the plot.

Data Analysis:

The data obtained was tested for correlation between prey availability and abundance of *H. hypnale* during different seasons and was analysed employing correlation coefficient to know whether prey availability across seasons influences the abundance of pit vipers.

PIT Tagging

The PIT tagging experiment was carried out at CWS (Hattipaul) since two species (*T. gramineus* and *H. hypnale*) were found in this transect and this transect exist in the premises of the forest department, this ensured that the tagged individuals were not being killed by the locals. *Trimeresurus malabaricus* was not found in the said transect and therefore was excluded from this experiment.

After capturing the pit vipers were immobilized by inserting their anterior half of the body into the optimum sized transparent plastic pipes (10, 15, 25 and 30 mm diameter) based upon their size. Small (2.2 x 12 mm) PIT tags (Trovan, Model- ID 100) were injected subcutaneously in the ventro-lateral part in the midbody of the adult snake to allow subsequent identification (Plate 2). The area where the tag was to be inserted was wiped with alcohol soaked cotton ball. The syringe was inserted between the first and second lateral scale rows (second scale from the belly) and pointed at a slight angle towards the ventral scales (Elbin and Burger, 1994; Keck, 1994; Jemison *et al.*, 1995; Buhlman and Tuberville, 1998; Roark and Dorcas, 2000). After inserting the tag the code of the tag was recorded by moving the recorder (LID571-ISO multi chip transponder reader) on the body of the snake where tag was inserted (Table: 3).

Seven individuals of *T. gramineus* (4 males, 3 females) and 6 females of *H. hypnale* were tagged. Later these snakes were transferred to the plastic box and their post tagging behaviour was observed for 30 minutes. Tagged snakes were released within 24 hours after assessing the physical condition of the snakes. None of the snakes suffered as a result of this experiment. The location of release of each pit viper was recorded. Search operation was carried out to recapture the tagged snakes on the eight day of their release. The morphological details such as snout vent length (SVL), caudal length (CL), total body length (TL) and body mass were recorded before release and after recapturing the snakes. When the snake was recaptured, the distance traveled by the snake from the release location was also recorded. The growth increments were calculated (final SVL minus initial SVL) for all the recaptured snakes. The change in mass was recorded and the increment was divided by the number of days between capture to provide a mean of daily rate of growth in mass over the intervening period.

Behavioural Study

The behavioural study was carried out following the methodology of Oliveira and Martins (2001), Blouin-Demers *et al.* (2007) Lin *et al.* (2007) and Sperry and Weatherhead (2009). As and when a pit viper was sighted the individuals were observed from distance of 5m for 15-30 minutes in order to record their movements and foraging behavior. For each snake encountered, its exact location and body posture (tightly coiled / active) were recorded. Further, tightly coiled pit vipers were categorized as sit-and-wait ambush foragers and outstretched (traveling/crawling) individuals as active. Adult pit vipers encountered during the survey may have been involved in other activities, such as habitat dispersal, mate-searching etc. Differences in behavior when located such as basking/ resting /concealed were also tested. Snakes were considered basking if they were exposed and immobile. When viper was immobile and coiled with its head in the center or laid its head on its body, it was deemed as being in resting position (Lin *et al.*

2007). To identify active or inactive individuals in the present analyses, individuals were considered active when the snake was exposed, either moving or coiled with the neck forming an S-coil, and the head lying over body coils and generally forming an angle 'Y' 20° in relation to the ground. Individuals were considered inactive if they were coiled and the head was laid on the body pointing downwards. When a pit viper was stationary with its neck and fore body positioned in a sigmoid shape, and its head pointed downward, it was deemed as being in a foraging position.

Foraging Behaviour

The feeding behavior of pit vipers in the field was visually observed till the prey was engulfed. Single individual of each species was housed and fed once in a week. Feeding behaviour was observed in detail for two months and analyzed precisely in captivity following the methodology of Tsai (2007). A single live prey was introduced into the housing of the pit viper. The capture position, direction of ingestion (anterior/posterior) and prey-handling tactics were observed and recorded for each feeding trial. Capture positions were classified in to four regions; (I) Anterior (head or neck), (II) mid anterior (shoulders, forelimbs or thorax), (III) mid posterior (abdomen or waist) and (IV) posterior (hips, hind limbs or tail).The entire feeding process was recorded using a camera (Nikon D-5000).The time taken from strike to full ingestion of the prey was recorded.

Data Analysis:

The difference in activity during day and night for each species separately was tested using One-way ANOVA. The correlation between the prey size and time taken for ingestion of prey by each species of pit viper was analyzed using correlation coefficient to know whether prey size influence the time taken for ingestion of prey. The difference between the prey size and time taken for the ingestion of prey by all the three species was tested using two-way ANOVA.

Phylogenetic study

Samples Collection:

The samples were collected from protected areas in Goa. The samples, immediately after collection, were transported to the Laboratory for the Conservation of Endangered Species (LaCONES), Centre for Cellular & Molecular Biology (CCMB) Annex I, Hyderabad.

Tail-tip biopsies were collected and preserved in 80% ethanol, or 100–200 μl of blood was collected from the caudal vein of caught specimens (all three species of pit vipers studied), in 5% EDTA, and preserved in 2ml SDS–Tris buffer (100mM Tris, 3% SDS). Whole genomic DNA was extracted from 0.01 to 0.02 g of ethanol-preserved muscle and from 200–500 μl of blood, using standard protocols (Sambrook *et al.*, 1989). The DNA was dissolved in TE buffer (10 mM Tris, 1 mM EDTA, pH 8.0) and quantified in 0.8% (w/v) agarose and also using UV-VIS spectrophotometer.

PCR amplification and sequencing:

The DNA isolated from both type of tissues was amplified using the Polymerase Chain Reaction (PCR). PCR is an advanced molecular biology technique for amplifying DNA exponentially, via enzymatic reaction *in vitro*. Partial sequence of Cytochrome *b* gene was obtained using primers cytbF (Kocher *et al.*, 1989) and cytbR (Verma and Singh, 2003). The 16S rRNA was amplified universal primer (Palumbi et al.,1991). PCR was set up in a 15 µl reaction volume. A master mix containing reagents mentioned in table: 4a was prepared and then equally dispensed into PCR tubes and DNA template was added to each tube. Standard precautions including the use of negative controls were taken to avoid contamination. The PCR was carried out in Thermal cycler (Applied Biosystems) as per conditions given in table: 4b. The annealing temperature (T_M) for cyt b gene was 52^0C and for 16S rRNA was 50^0C. PCR products were electrophoresed in 2.5% agarose gel by loading molecular weight marker in first well. The gel was visualized under UV light in the Gel documentation system (BioRad).

Phylogenetic Analysis:

MtDNA sequences (Cyt b, 480bp and 16S rRNA, 510bp) were initially edited and aligned using Autoassembler software (Applied Biosystem, USA). The edited sequences were aligned using CLUSTALX (Thompson et. al. 1997), visually checked. Initial sequence comparison, measures of variability and phylogenetic relationships among the various species of vipers were examined using Neighbor-Joining analysis based on Kimura two-parameter (Kimura 1980) distance with gamma correction, as implemented in MEGA 4.0 (Tamura et al. 2007). For Maximum Parsimony (MP) analysis, heuristic searches were performed with tree bisection reconnection (TBR) branch swapping, 1000 replicates, stepwise addition starting tree and random sequence addition option in Mega 4.0. *Daboia russelli* (Russell viper) was used as an out group. The nucleotide (Pi) as well as the haplotypes (Hd) diversity were scored using DnaSP v5 (Rozas, 2009). Tests for departures from neutrality were performed based on Tajima D test (Tajima, 1989) using DnaSP v5.

Threats

Threats to pit vipers in all the study sites were assessed by local surveys and field observations. Potential predators of pit vipers were recorded.

Tourism threat:

Threats from tourism was assessed by studying encounter rate of pit vipers in the transect frequently visited by tourists. This study was conducted in BMWS, CWS and BWS. Data of the number of visitors in these study sites for a period of 5 years (Jan 2005- Jan 2010) was procured from the Forest Department. The study sites include a number of camp sites, heavily used hiking trails, there is regular contact between people and snakes in these areas. The data obtained was used to determine if the tourism activity affected the abundance and distribution of pit vipers.

Data Analysis:

The influence of number of tourists visiting the study sites (BWS, CWS, and BMWS) on the abundance of pit vipers was tested using one-way ANOVA.

Statistical Analysis

All the calculations i.e. One-way ANOVA, Two-way ANOVA, Correlation coefficient and plotting of graphs were carried out using the Microsoft Excel Software 2007. Differences of $P<0.05$ was regarded as statistically significant. Box-plots were plotted using Microsoft Excel Software 2003.

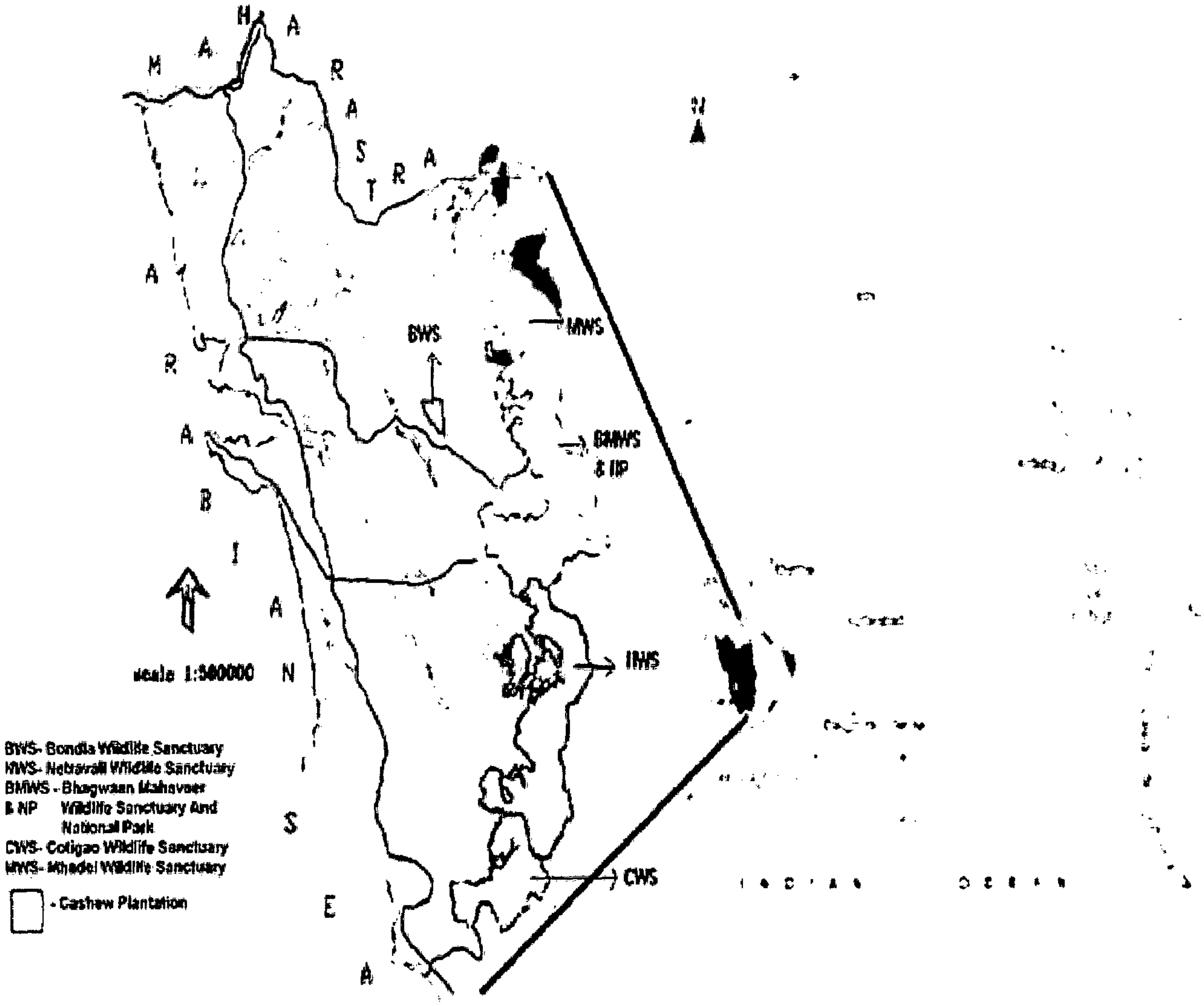


Figure 1: Map of Goa showing the study sites and cashew plantations adjoining and within the study sites

Table 1: List of forest types present in the study areas

FOREST TYPE/SUB TYPE	SANCTUARY				
	MWS	BWS	BMWS and NP	NWS	CWS
1. **1A/C4** West coast tropical evergreen	√		√	√	
2. **E1** Cane brakes	√		√	√	√
3. **E2** Wet bamboo brakes	√		√	√	√
4. **3BC1IC** Slightly moist teak forest	√		√	√	
5. **3B/C2** Southern moist mixed deciduous forests		√	√	√	√
6. **8A/DSI** South Indian sub-tropical savannah woodland	√		√	√	√
7. **8A/C2** Southern sub-tropical hill forest			√	√	√
8. **3B/C2/2B1** Southern secondary moist mixed deciduous forest	√	√		√	√
9. **2AC2** West coast semi evergreen	√	√	√	√	√
10. **1E3** Moist bamboo brakes	√		√		
11. **2/E4** Lateritic semi- evergreen forest	√		√		

Table 2: Geographical locations of the study transects

a. Mhadei Wildlife Sanctuary

Sr. No	Transect name	Latitude	Longitude	Altitude
1	Surla Sada (SS)	E 074° 10' 40.7"	N 15° 39' 25.3"	818m
2	Surla Cashew Plantation (SCP)	E 074° 11' 22.9"	N 15° 35' 46.5"	175 m
3	Surla Devrai (SD)	E 074° 10' 27.6"	N 15° 39' 41.0"	770m
4	Surla Village (SV)	E 074° 10' 22.7"	N 15° 40' 09.0"	715m
5	Krishnapur Road (KR)	E 074° 12' 15.7"	N 15° 31' 06.8"	76m
6	Nanode (N)	E 074° 35' 32.6"	N 15° 35' 11.1"	137m
7	Sathre (S)	E 074° 13' 17.7"	N 15° 37' 08.1"	130m
8	Paikul (P)	E 074° 07' 53.5"	N 15° 26' 44.6"	26m
9	Uste (UT)	E074° 11' 35.3"	N 15° 33' 48.0"	117m
10	Guleli (GU)	E 074° 08' 33.1"	N 15°27' 14.9"	36m
11	Kumthal (KU)	E 074° 12' 27.0"	N 15° 30' 51.8"	75m
12	Ivrem (IV)	E 074° 09' 04.0"	N 15° 38' 08.0"	132m
13	Velge (VE)	E 074° 08' 52.8"	N 15° 30' 53.0"	45m

b. Bhagwan Mahavir Wildlife Sanctuary and National Park

Sr. No	Transect name	Latitude	Longitude	Altitude
1	Dudhsagar Road (DR)	E 074° 13' 57.5"	N 15° 22' 41.3"	127m
2	Dudhsagar Area (DA)	E 074° 18' 25.8"	N 15° 18' 56.7"	249m
3	Sonaulim (SO)	E 074° 17' 48.7"	N 15° 18' 42.4"	153m
4	Vasant Bandara (VB)	E 074° 15' 24.1"	N 15° 24' 02.6"	142m
5	Avdem Mol (AM)	E 074° 14' 48.4"	N 15° 23' 57.9"	120m
6	Nandran (NA)	E 074° 14' 13.3"	N 15° 23' 24.1"	103m
7	Sunset Point Road (SPR)	E 074° 14' 45.6"	N 15° 23' 42.2"	114m
8	Dongurlim (DO)	E 074° 13' 09.0"	N 15° 16' 48.4"	230m
9	Khachkon (KH)	E 074° 14' 38.8"	N 15° 23' 40.7"	78m
10	Tambdi surla temple (TST)	E 074° 17' 50.2."	N 15° 18' 40.3"	140m
11	Tambdi surla Vajra Sakal (TSVS)	E 074°15 25.0	N 15° 26' 16.0	237m
12	Kollem Road (KR)	E 074° 14' 14.0"	N 15° 21' 37.8"	120m
13	Camp site (CS)	E 074° 15' 10.7"	N 15° 20' 31.8"	92m
14	Mollem office premises (MOP)	E 074° 13' 48.0"	N 15° 22' 37.8"	94m

c. Netravali Wildlife Sanctuary

Sr. No	Transect name	Latitude	Longitude	Altitude
1	Shigone (SH)	E 074° 13' 29.8"	N 15° 08' 33.1"	55m
2	Bhatti (BH)	E 074° 13' 55.2"	N 15° 10' 28.6"	125m
3	Maina Pee (MP)	E 074° 14' 05.6"	N 15° 04' 48.9"	97m
4	Savri Waterfall (SW)	E 074° 13' 25.1"	N 15° 04' 14.7"	121m
5	Verle (VE)	E 074° 14' 31.9"	N 15° 02' 45.4"	551m
6	Saljini (SA)	E 074° 14' 37.0"	N 15° 00' 31.6"	525m
7	Tudov (TU)	E 074° 14' 37.6"	N 15° 03' 42.3"	421m

d. Cotigao Wildlife Sanctuary

Sr. No	Transect name	Latitude	Longitude	Altitude
1	Hattipaul (HA)	E 074° 06' 31.9"	N 14° 59' 04.7"	84m
2	Tree top Area (TTA)	E 074° 09' 40.4"	N 14° 58' 20.3"	121m
3	Tulsimol (TM)	E 074° 11' 07.5"	N 14° 57' 16.0"	124m
4	Bela Road (BR)	E 074° 08' 29.3"	N 14° 58' 37.9"	103m
5	Morpholmol (MP)	E 074° 11' 28.4"	N 14° 58' 21.4"	52m
6	Depo Area (DA)	E 074° 06' 31.8"	N 14° 59' 03.0"	91m

e. Bondla Wildlife Sanctuary

Sr. No	Transect name	Latitude	Longitude	Altitude
1	Dam Area (DAA)	E 074° 06' 02.6"	N 15° 26' 23.5"	247m
2	Canteen (CAT)	E 074° 06' 37.8"	N 15° 25' 57.5"	147m
3	Bondla Mollem Road (BMR)	E 074° 08' 23.1"	N 15° 24' 47.3"	89m
4	Zoo (ZO)	E 074° 06' 29.2"	N 15° 25' 45.5"	143m
5	Garden Area (GA)	E 074° 06' 27.7"	N 15° 25' 55.9"	156m

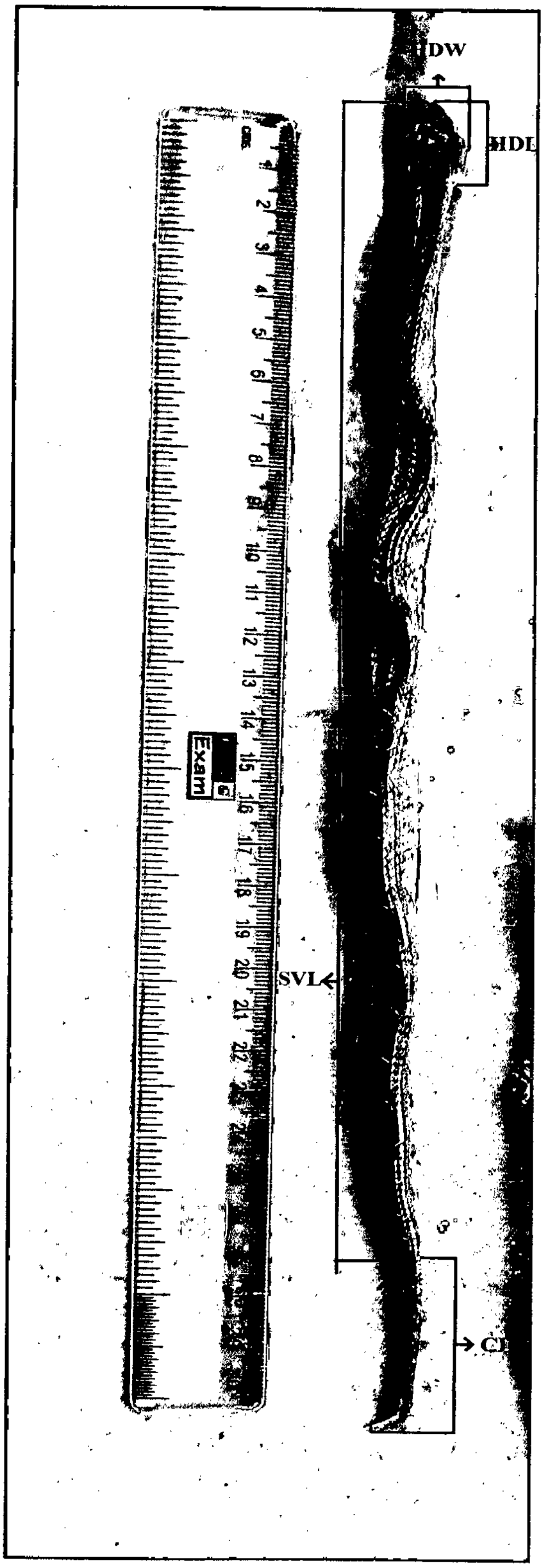


Plate 1: Morphometric measures of the pit vipers.

Table 3: Pit tag codes injected in pit vipers

DATE	SPECIES	PLACE	TAG CODES
20/07/07	*T. gramineus* ♂	Cotigao	0006830E48
21/07/07	*H. hypnale* ♀	Cotigao	000683035D
25/07/07	*H. hypnale* ♀	Cotigao	000683053B
25/07/08	*T. gramineus* ♀	Cotigao	0006834441
16/08/07	*T. gramineus* ♂	Cotigao	000682FE50
16/08/07	*T. gramineus* ♂	Cotigao	000683642B
28/03/08	*H. hypnale* ♀	Cotigao	000683126C
01/04/08	*T. gramineus* ♂	Cotigao	00068301E4
04/04/08	*H. hypnale* ♀	Cotigao	00068369E2
14/09/08	*T. gramineus* ♀	Cotigao	0006833948
15/09/08	*T. gramineus* ♀	Cotigao	000683679F
05/10/08	*H. hypnale* ♀	Cotigao	0006830FED
07/10/08	*H. hypnale* ♀	Cotigao	000683308

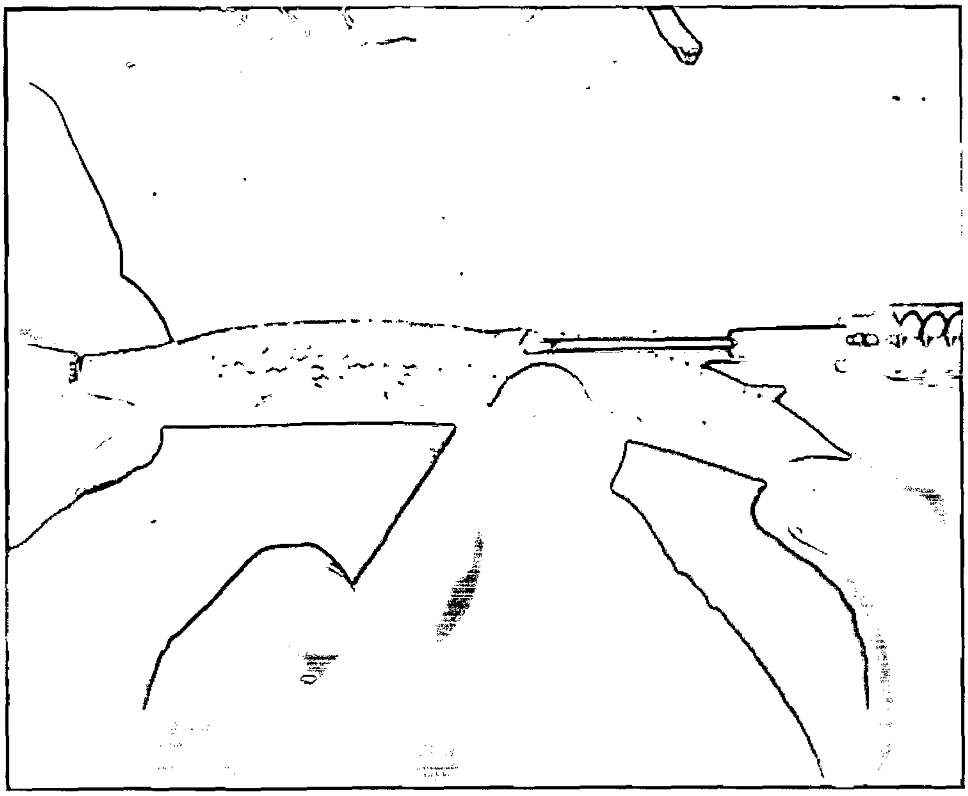


Plate 2: Image showing the process of Pit tagging in *T. gramineus*

Table 4a: PCR reaction mixture

Component	Volume (μl)
10X PCR buffer	1.5
$MgCl_2$ (25 mM)	2.0
dNTPs (2.5 mM)	1.5
BSA (10X)	1.5
Forward primer (5 pM/μl)	0.3
Reverse primer (5 pM/μl)	0.3
Taq polymerase (5 units/μl)	0.2
Mili Q	3.7
Genomic-DNA (10 ng/μl)	4.0

Table 4b: Conditions for PCR

Steps	Conditions
1	95^0C for 3 min
2	94^0C for 50 sec
3	52^0C for 50 sec for cyt b and 50^0C for 50 sec for 16S rRNA
4	72^0C for 1:20 min
5	Go to step 2,34 times
6	72^0C for 7 min
7	15^0C forever

Distribution Pattern and Abundance

Fourty five transects were sampled during the present study and 356 pit vipers belonging to 3 species viz *T. gramineus, T. malabaricus and H. hypnale* were recorded (Plate 3 a-c). *H. hypnale* was the most abundant species contributing to 46.63% (n = 166) and was found in 31 transects followed by *T. gramineus* and *T. malabaricus* which contributed to 28.09 % (n = 100) and 25.28% (n = 90) and were found in 18 and 11 transects respectively (Table 5 a-e).

Year wise Abundance:

The number of individuals of all the three species sighted during the present study is given in (Table 6, Figure 2).All the three species of pit vipers showed variation in their numbers. It was observed that maximum number of pit vipers (*T. malabaricus* = 48, *T. gramineus* = 61 and *H. hypnale* = 97) were sighted in the year 2006-2007 and minimum (*T. malabaricus* = 5, *T. gramineus* =5 and *H. hypnale* = 14) was in the year 2008-2009. Table 6/Figure 2 indicates that all the three species of pit vipers showed a sharp increase in their number in the second year of the study, which then showed a sharp decrease in the third year followed by a gradual decrease in the fourth year. One-way ANOVA (analysis of variance) for each species with respect to 4 years depicted a significant variation in the abundance of *H. hypnale* ($F=6.32$, $df= 3$, $p= 0.004$), the abundance of *T. malabaricus* and *T. gramineus* varied insignificantly ($p >0.05$).

Site wise abundance and distribution:

The distribution of pit vipers is represented in figure: 3 the abundance of pit vipers varied in different study locations (Table: 7 /Figure: 4). All three species of pit vipers were observed in all the study locations, except the BWS, where only *T. gramineus* was found. One-way ANOVA study for each site with respect to the three species depicted an insignificant ($p>0.05$) pattern of abundance and distribution of each species with respect to the sites. Further, one-way ANOVA for each species with respect to five sites showed that the abundance of each species varied insignificantly ($p>0.05$) with respect to the five sites. Amongst the four sites where *T. malabaricus* was found, NWS had the lowest occurrence, contributing to 14.4% of the total found in all the sites, whereas, it had highest occurrence at MWS contributing to 35.5 %. Amongst the five sites where *T. gramineus* was found, it had lowest occurrence at BWS, contributing to 11.57 %, whereas, it had highest occurrence at CWS contributing to 30.52% of the total individuals found in all the sites. However, amongst the four sites where *H. hypnale* was found it had lowest occurrence at NWS contributing to 18.67 % and had highest occurrence at BMWS contributing to 34.93%.

Distribution along the Altitudinal gradient:

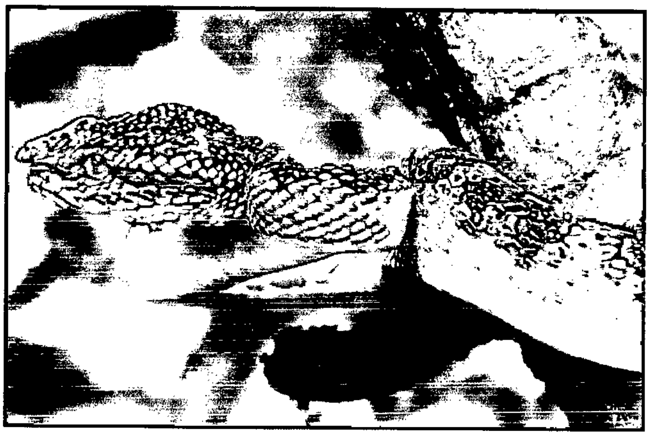
The abundance of *H. hypnale* and *T. gramineus* was highest at low altitude and lowest at high altitude. However, *T. malabaricus* showed high abundance at low and high altitude and lowest abundance at mid altitude (Table: 8) and was observed at an altitude above 200m. They were sighted at higher elevation in all the sites except in CWS; where it was recorded below 200m and ranged from 123 to 800 m. *Trimeresurus gramineus* and *H. hypnale* were found from 37 to 672 m and 35 to 672 m respectively (Figure: 5). *Hypnale hypnale* showed highest abundance at an altitude range of 20-100m and showed the lowest abundance at an altitudinal range between 300 to 800m. *Trimeresurus gramineus* showed highest abundance at an altitude range of 20 to 100m and lowest at an altitudinal range between 201 to 500m and 601 to 800m *Trimeresurus malabaricus* showed highest abundance at an altitude range of 100-200m and lowest abundance at an altitudinal range between 100 to 700m. Two-way ANOVA showed a significant pattern of distribution of all the three species along the altitudinal gradients ($F= 1.93$, $df= 14$, $p= 0.03$).

Seasonal distribution and abundance:

Distribution of pit vipers varied among seasons. During monsoon they were found in all 45 transects, whereas, in summer and winter they were observed in 35 transects (TU, DA, DAA, CAT, ZO, GA, TTA, HA, TD, SA, VL, SW, MP, BH, SH, MOP, CS, TSVS, TST, DO, NA, VB, SO, DA, DR, VE, IV, KU, GU, S, N, KP, SCP, P, UT) which include transects having water bodies in the vicinity and transects in the cashew plantations, and were restricted to patches near moist areas. The abundance of all three species of pit vipers varied considerably through seasons (Table: 9, Figure: 6).During monsoons, their abundance was high in all transects. The number of individuals of *T. malabaricus* sighted during summer was 7; in monsoon it showed 900% increase from summer i.e. 70 individuals were sighted during monsoon, while in winters it showed 81.43 % decrease from monsoon i.e. 13 individuals were sighted in winter. Similarly the number of individuals of *T. gramineus* and *H. hypnale* sighted during summer was 10 and 38 respectively. In monsoon *T. gramineus* showed 650% increase from the summer i.e. 75 individuals were sighted during monsoon, while in winter it showed 80% decrease from the monsoon i.e. 15 individuals were sighted during winter. However, 99 individuals of *H. hypnale* were sighted during monsoon, showing an increase of 160.53 % from the summer and 29 individuals were sighted during winter showing a reduction of 70.71% from monsoon. Amongst the three species *H. hypnale* had the highest encounter rate during all the seasons.

Two-way ANOVA showed that the abundance of pit vipers varied significantly with seasons (*T. malabaricus* [$F = 3.20$, $p = 0.00058$], *T. gramineus* [$F = 3.20$, $p = 0.00028$] and *H. hypnale* [$F = 3.20$, $p = 0.015$]). However, the abundance did not change significantly during each season when compared between sites.

(a)



(b)

(c)

Plate 3: Pit viper species found in Goa, (a) *T. gramineus,* (b) *T. malabaricus* and (c) *H. hypnale*

Table 5: List of transects in which pit viper species were encountered

a. Mhadei Wildlife Sanctuary

Sr. No	Transect name	*T. malabaricus*	*T. gramineus*	*H. hypnale*
1	Surla Sada (SS)	•		
2	Surla Cashew Plantation (SCP)			•
3	Surla Devrai (SD)	•		
4	Surla Village (SV)	•		
5	Krishnapur (KP)		•	•
6	Nanode (N)		•	•
7	Sathre (S)	•		•
8	Paikul (P)		•	
9	Uste (UT)		•	
10	Guleli (GU)			•
11	Kumthal (KU)		•	•
12	Ivrem (IV)	•		•
13	Velge (VE)			•

b. Bhagwan Mahaveer Wildlife Sanctuary and National Park

Sr. No	Transect name	*T. malabaricus*	*T. gramineus*	*H.hypnale*
1	Dudhsagar Road (DR)			•
2	Dudhsagar Area (DA)	•		
3	Sonaulim (SO)	•		•
4	Vasant Bandara (VB)			•
5	Avdem mol (AM)			•
6	Nandran (NA)		•	•
7	Sunset Point Road (SPR)			•
8	Dongurlim (DO)		•	•
9	Khachkon (KH)			•
10	Tambdi surla temple (TST)		•	•
11	Tambdi surla Vajra Sakal (TSVS)			•
12	Kollem Road (KR)		•	
13	Camp site (CS)			•
14	Mollem office premises (MOP)			•

c. **Netravali Wildlife Sanctuary**

Sr. No	Transect name	*T. malabaricus*	*T. gramineus*	*H. hypnale*
1	Shigone (SH)			•
2	Bhatti (BH)			•
3	Maina Pee (MP)	•		
4	Savri Waterfall (SW)			•
5	Verle (VL)		•	
6	Saljini (SA)		•	
7	Tudov (TD)	•		

d. **Cotigao Wildlife Sanctuary**

Sr. No	Transect name	*T. malabaricus*	*T. gramineus*	*H. hypnale*
1	Hattipaul (HA)		•	•
2	Tree top Area (TTA)	•		•
3	Tulsimol (TU)	•		•
4	Bela Road (BR)			•
5	Morpholmol (M)			•
6	Depo Area (DA)		•	•

e. **Bondla Wildlife Sanctuary**

Sr. No	Transect name	*T. malabaricus*	*T. gramineus*	*H. hypnale*
1	Dam Area (DAA)		•	
2	Canteen (CAT)		•	
3	Bondla Mollem Road (BMR)		•	
4	Zoo (ZO)		•	
5	Garden Area (GA)		•	

Table 6: The number of individuals of all the three species sighted during different years

Year	T. malabaricus	T. gramineus	H. hypnale
2005 – 2006	17	17	19
2006 – 2007	49	61	97
2007 – 2008	19	17	36
2008 – 2009	5	5	14

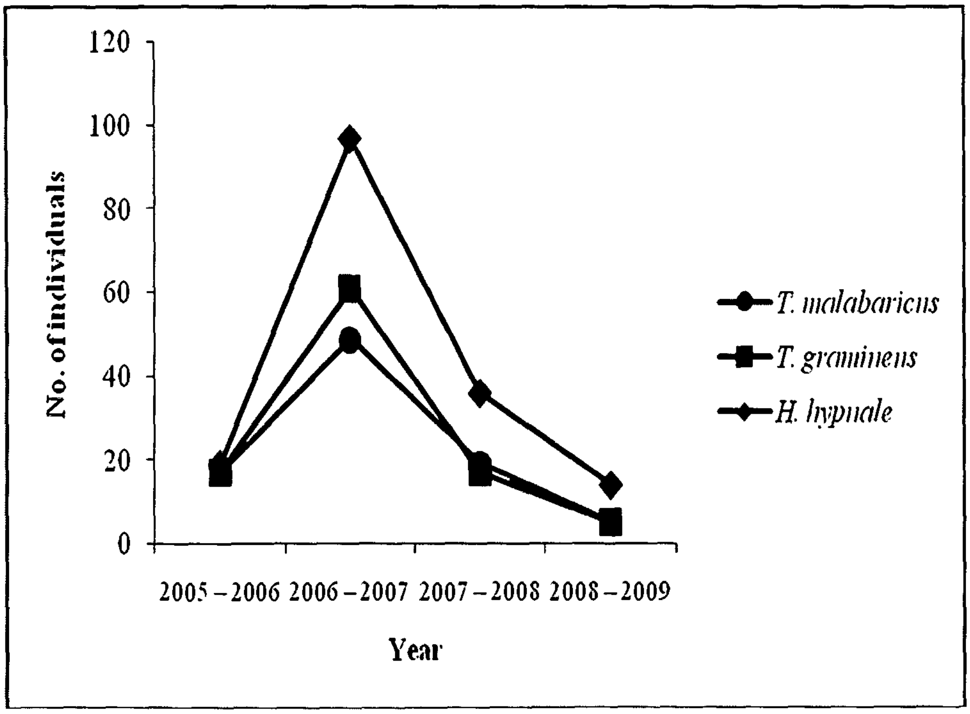


Figure 2: Graph showing the number of individuals of all the three species sighted during different years

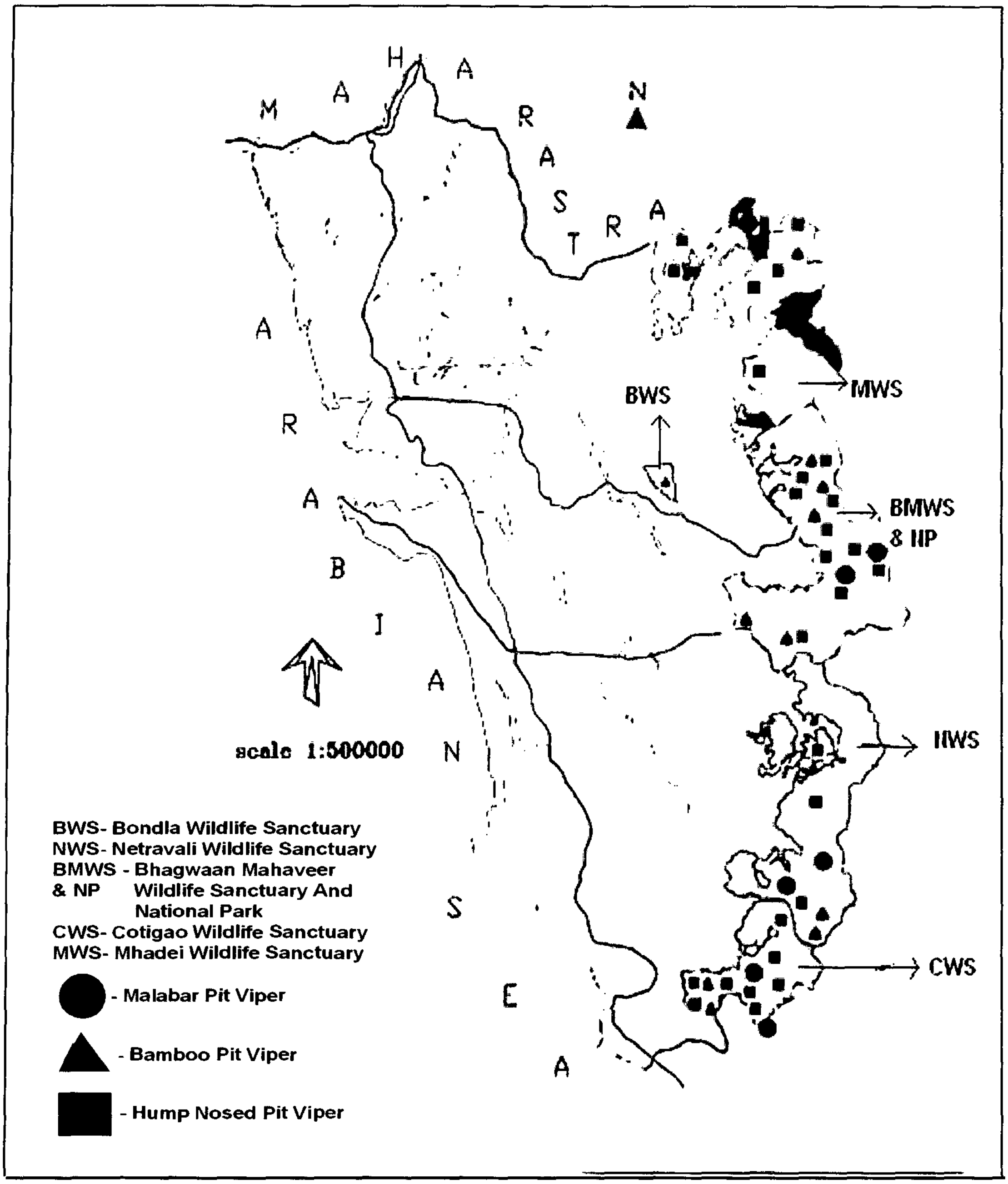


Figure 3: Map of Goa showing the distribution of pit viper species in the study sites

Table 7: Observation of pit vipers in different study sites

Study Area	Number of individuals of each species		
	T. malabaricus	*T. gramineus*	*H. hypnale*
CWS	31	34	38
BWS	0	11	0
MWS	32	21	39
BMWS	14	15	58
NWS	13	19	31

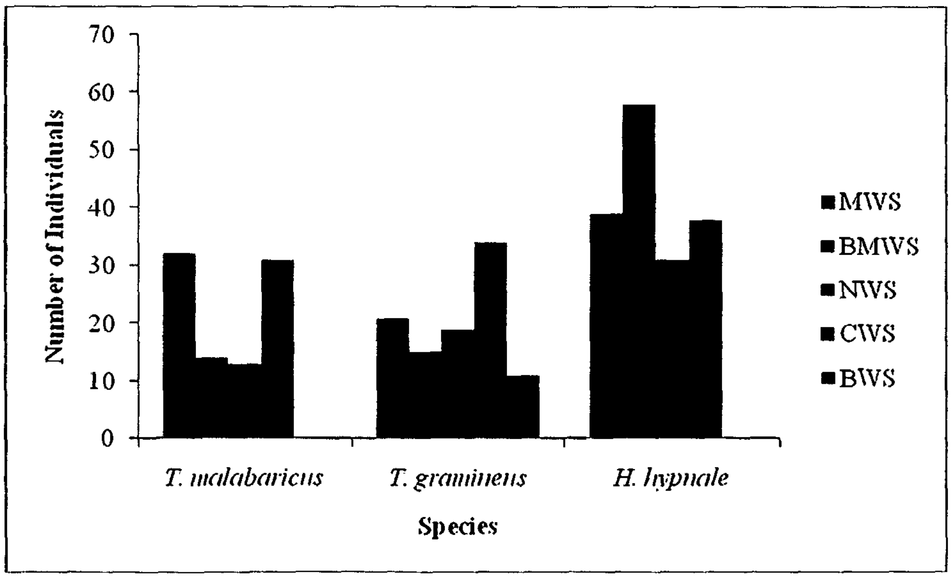


Figure 4: Graph showing abundance of pit vipers in different study sites

Table 8: Abundance of pit vipers at different altitudinal range

Altitudinal Range(m)	***T. malabaricus***	***H. hypnale***	***T. gramineus***
20-100	0	77	57
101-200	33	63	14
201-301	4	21	7
301-400	5	2	3
401-500	4	1	4
501-600	17	1	14
601-700	7	1	1
701-800	20	0	0

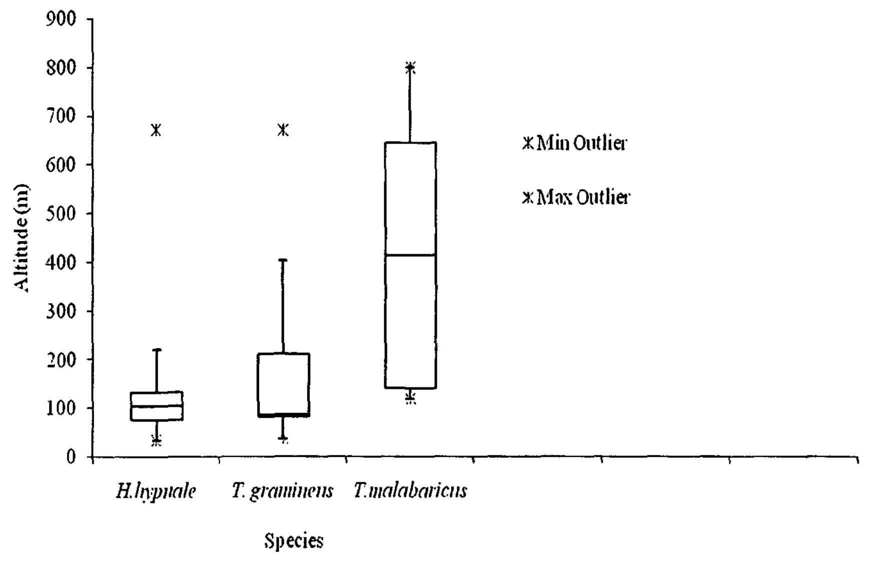


Figure 5: Graph showing Altitude (in M) at which the Pit Viper Species were observed in Goa. The box represents the 50% of the population, the horizontal line in the box represents the mean, the whiskers represent 75% of the remaing 50 % of the population and points represent the min amd max height attained by the individuals.

Table 9: Variations in the observation of pit vipers among different seasons

Species	Season		
	Summer	**Monsoon**	**Winter**
T. malabaricus	7	70	13
T. gramineus	10	75	15
H. hypnale	38	99	29

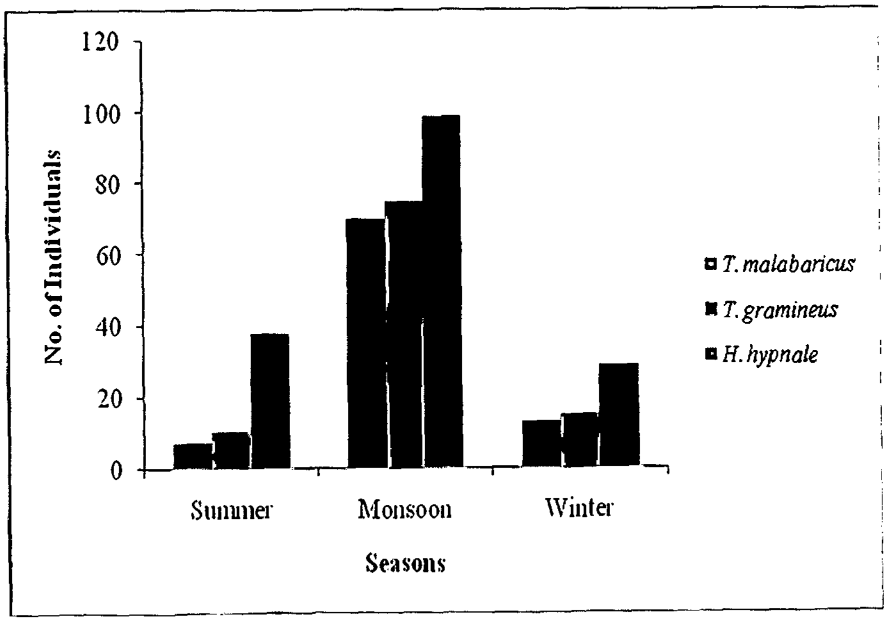


Figure 6: Graph showing variations in the observation of pit vipers among different seasons in the Western Ghats of Goa

Habitat ecology

The habitat (forest types) composition in each of the study area and the habitat (forest types) preferred by each species is listed in table 10 and table 11 respectively. It was observed that the habitat composition within each snakes home range differ from the habitat composition within the total study area. All the three species of pit vipers were seen in eight out of the eleven forest types present in the study areas. Each species exhibited habitat preference and pit vipers were restricted to the forest types which they preferred. It was observed that all the three species were found in west coast tropical evergreen, slightly moist teak forest, south Indian sub-tropical savannah woodland, southern sub-tropical hill forest, southern secondary moist mixed forest, west coast semi evergreen, moist bamboo brakes, and lateritic semi- evergreen forest. Whereas, in cane brakes and wet bamboo brakes only *T. gramineus* and *H. hypnale* was found, while in southern moist mixed deciduous forests, only *T. gramineus* and *T. malabaricus* were encountered. Thus, all the three species preferred a broad range of forest types.

Trimeresurus malabaricus selected home ranges that include area with thick vegetation. Amongst the total 90 individuals of *T. malabaricus* 87.78 % were encountered in forest habitat, whereas, the remaining 12.22 % were present in forest edge habitat. It was also noticed that the 12.22% of *T. malabaricus* that preferred forest edge habitat were encountered at regions of higher altitude. On the contrary, amongst the 100 individuals of *T. gramineus* 40% were encountered in the forest habitat, whereas, 60% were observed in the forest edge habitat. Amongst the 166 individuals of *H. hypnale* 56.03% individuals were found in the forest edge habitat and 43.97% were encountered in the forest habitat. *Hypnale hypnale* selected home ranges that included areas with thick leaf litter. None of the three species were found in open habitats (Table: 12, Figure: 7). All the three species of pit vipers preferred diverse habitat and were spread over the entire available space during the monsoon, whereas, they were restricted to cool and moist places during winter and summer. One-way ANOVA between each species and the habitat used (forest, forest edge and open) showed that the habitat utilization by *T. malabaricus* varied significantly ($F=7.74$, $df=2$, $p=0.006$), whereas *T. gramineus* and *H. hypnale* showed insignificant pattern of habitat use.

Habitat preference deferred in males and females in all the three species. It was observed that 87.5% out of 56 females and 88.23% of 34 males of *T. malabaricus* preferred forest habitat (Table: 13, Figure: 8). Whereas, in *T. gramineus* and *H. hypnale* it was observed that both males and females were often encountered in forest edge habitat. Thus, 45.28% of 53 females of *T. gramineus* were encountered in forest habitat while 54.72% were encountered in forest edge habitat and 34.05% of 47 males were found in forest habitat while, 65.95% were found in forest edge habitat (Table:14, Figure: 9). While, 56.48% of 108 females and 55.17% out of 58 males of *H. hypnale* were encountered in forest edge habitat and 43.52% females and 44.83% males were encountered in forest habitat (Table: 15, Figure: 10). One-way ANOVA analysis showed that the preference of habitat types by both the sexes of *T. malabaricus* varied significantly, [males ($F=6.53$, $df=1$, $p=0.033$) and females ($F=6.03$, $df=1$, $p=0.039$)], whereas, the preference for habitat type by both the sexes of *T. gramineus* and *H. hypnale* differed insignificantly ($p > 0.05$).

During the present study it was noted that *T. malabaricus* and *T. gramineus* did not show any change in habitat preference during different seasons except that they were concentrated near cool and moist places that were available in the transects during summer and winter. It was observed that during the post monsoon, winter and late summer *H. hypnale* moved to the adjoining cashew plantations. *Hypnale hypnale* was encountered in the cashew plantations in almost all the seasons except monsoon. Unlike the other two species which were not sighted in the cashew plantations. However, *T. gramineus* was sighted in the cashew plantation only once during the course of this study. The average number of individuals of *H. hypnale* sighted in the forest area and the cashew plantation during different seasons is given in table: 16; figure: 11. One-way ANOVA) showed that the preference of *H. hypnale* for forest area and cashew plantation with respect to different seasons varied insignificantly ($p>0.05$). It was also noted that the population which moved to the adjoining cashew plantations on an average had low male: female ratio i.e. 0.22 (Table: 17, Figure: 12). Thus out of the total individuals encountered in cashew plantation during the course of the study 81.81% were females, while most of the females that moved to the cashew plantations were gravid females. Thus, 65.9 % of the total females sighted in the cashew plantations were gravid females. Two-way ANOVA showed a significant habitat preference by gravid and non gravid females of *H. hypnale* ($F=11.7$, $df= 1$, $p= 0.003$).

Microhabitat:

The temperature and humidity range during different seasons is given in table: 18. The average temperature and humidity of the area during the present study ranged from

20.88 ± 5.25 ^{0}C to 32.44 ± 0.88 ^{0}C and $53 \pm 4\%$ to $93 \pm 2\%$ respectively. The temperature and humidity varied during different seasons. The microhabitat use varied seasonally in all the three species, during monsoon they were found in all the transects, whereas, in summer and winter they were observed in 35 transects which include transects having water bodies in the vicinity, thick vegetation and transects in the cashew plantations (for *H. hypnale*).

Microhabitat assessment for arboreal species:

Trimeresurus malabaricus and *T. gramineus* were observed mostly on vegetation and rarely on ground. Out of 90 individuals of *T. malabaricus* encountered during the present study 85.55% (n=77) were encountered on the vegetation while 14.45% (n=13) were found on ground (3 were found while crossing the road [at night] and 10 were found on rocks near the water body). It was noted that all the individuals of *T. malabaricus* encountered while crossing the road were males (were encountered during the monsoon), 70 % of the individuals encountered on the rocks were females. It was observed that 63.64% of the individuals encountered on the vegetation were females and 36.36 % were males and 68.84% of the total individuals were sighted in the areas having thick tree canopy cover, while 31.16% were encountered in areas having sparse tree canopy cover.

Out of 100 *T. gramineus* that were encountered during the study 94% (n=94) were encountered on the vegetation whereas, 6% (n=6) were encountered on ground (while crossing the road at night). It was observed that 83.34% individuals encountered while crossing the roads were males, whereas 55.32% individuals encountered on the vegetation were females and 44.68% were males. It was also observed that 34.04% of the total individuals sighted on vegetation were sighted in the areas having thick tree canopy cover, while 65.96% were encountered in area having sparse tree canopy cover. The tree canopy cover structure differed in different seasons. However; both these arboreal pit vipers utilized only those regions having thick tree canopy cover. The arboreal pit vipers exhibited no preference for vegetation structure at low ambient temperature (monsoon), except for an apparent avoidance of vegetation with bare branches and no leaves. However, during summer they were distributed in the regions with thick tree canopy and thick vegetation.

The tree species utilized by *T. malabaricus* and *T. gramineus* is given in table: 19. One-way ANOVA showed no significant difference ($p > 0.05$) between tree species utilization when compared between *T. malabaricus* and *T. gramineus* and also when compared between males and females of each species separately. Other associated flora and fauna of *T. malabaricus* and *T. gramineus* are listed in Appendix 1 and 2.

Perch Height:

Amongst pit vipers observed in vegetation the mean perch height for *T. malabaricus* was 1.56 ± 0.07 m (mean ± SE) and ranged from 0.60 to 3.35 m. The mean perch height did not differ much when compared between males and females. The females attained a mean perch height of 1.56 ± 0.08 m while males attained a mean perch height of 1.57 ± 0.11m (Figure: 13). one-way ANOVA showed no significant difference ($p > 0.05$) in perch height between males and females of *T. malabaricus*. There was a positive correlation between body length and perch height attained by males ($r=0.02$, $p> 0.05$) as well as females ($r=0.102$, $p> 0.05$) of *T. malabaricus*. The mean perch height for *T. gramineus* was 1.48 ± 0.06 m (mean ± SE) and ranged from 0.54 to 3.04 m. The mean perch height did not differ much when compared between males and females. The females attained a mean perch height of 1.50 ± 0.08 m while the males attained a mean perch height of 1.51 ± 0.08 m (Figure: 14). one-way ANOVA showed no significant difference ($p > 0.05$) in perch height between males and females of *T. gramineus*. There was a positive correlation between body length and perch height attained by males ($r=0.027$, $p> 0.05$) and females ($r=0.108$, $p> 0.05$) of *T. gramineus*. The arboreal pit vipers did not show any preference for the perch height during different seasons.

Perch Diameter:

Amongst pit vipers encountered in vegetation the mean perch diameter (diameter of the branch) utilized by *T. malabaricus* (n=50) was 42.5 ± 1.78 mm (mean ± SE) and ranged from 21 to 67 mm. The preference for perch diameter differed when compared between males and females. The utilization of mean perch diameter by females was 46.7 ± 2.54 mm while males utilized a mean perch diameter was 38.4 ± 2.26mm (Figure: 15). one-way ANOVA showed significant difference ($F= 5.83$, $df= 1$, $p= 0.019$) in perch diameter used by males and females of *T. malabaricus* . There was a positive correlation between body mass and perch diameter preferred when tested for males ($r =0.74$, $p=0.001$) and females ($r= 0.71$, $p= 0.001$). The mean perch diameter for *T. gramineus* was 39.28 ± 1.40 mm (mean ± SE) and ranged from 19.8 to 62.1 mm. Preference for mean perch diameter differed when compared between males and females. The mean perch diameter utilized by in females was 42.85 ± 2.06 mm while males utilized a mean perch diameter of 35.71 ± 1.73 mm (Figure: 16). Analysis of variance (one-way ANOVA) showed significant difference ($F= 7.32$, $df= 1$, $p= 0.008$) in perch diameter used by males and females of *T. gramineus* . There was a positive correlation between body mass and perch diameter preferred when tested for males ($r = 0.17$, $p> 0.05$) and females ($r = 0.83$, $p> 0.05$).

Location on the branches where arboreal pit vipers were found:

The location on the branches where *T. malabaricus* and *T. gramineus* were found differed. It was observed that *T. malabaricus* mostly preferred distal position on the branches followed by middle and apical. Thus 70.13% (n= 54) of the individuals sighted on the vegetation occupied distal portion whereas, 22.07% (n= 17) and 7.8 % (n=6) inhabited middle and apical regions of the branches respectively (Table 20, Figure 17). Among the male and female *T. malabaricus* it was observed that 68.52% of the total individuals encountered at the distal position of the branch were females, whereas, 31.48% were males. The females contributed to 58.83% of the total individuals encountered on the middle portion of the branch and males contributed to 41.17%, whereas, 33.33% females and 66.67% males inhabited apical region (Table: 21, Figure :18).

On the contrary, *T. gramineus* mostly preferred middle segment of the branches followed by apical and distal, 58.51 % (n= 55) of the individuals sighted on the vegetation occupied middle portion whereas 31.92 % (n=30) and 9.57% (n=9) inhabited apical and distal regions of the branches respectively (Table :22, Figure :19). Among the

T. gramineus sighted on the middle region of the branch 52.54% were females and 40.67% were males. Amongst the individuals encountered on the apical portion of the branch 73.07% were females and 42.30% were males, whereas, 22.22% females and 77.77% males inhabited distal region.

The arboreal pit vipers did not show any preference for the position on branch during different seasons. Two-way ANOVA showed a significant ($F=10.74$, $df=2$, $p=0.01$) difference in the utilization of branch position by each species of arboreal pit viper. Whereas, the same was insignificant ($p>0.056$) when tested for sexes of each species.

Thermal profile:

The ambient temperature at a height of every 30 cm from the ground up to the position of pit viper showed decline during summer (n=5; 2 *T. malabaricus* and 3 *T. gramineus*) whereas, it elevated during monsoon (n=5; 3 *T. malabaricus* and 2 *T. gramineus*). On all five sampling occasions during summer the ambient temperature was generally found to be high and averaged about 0.42 °C, higher on the ground than at the position where pit vipers were located on the trees. It was also noted that in summer the ambient temperature at 60 cm above the point where pit viper was located on the tree was high with an average of 0.24 °C higher than the ambient temperature at the position of pit viper (Figure: 20). On all five sampling occasions during monsoon the ambient temperature was generally found to be low and averaged about 0.3 °C, lower on the ground than at the position where pit vipers were located on the trees. It was also noted that the ambient temperature at 60 cm above the point where pit viper was located on the tree was low, with an average about 0.18 °C lower than the ambient temperature at the position of pit viper (Figure: 21).

Microhabitat assessment of terrestrial species:

Hypnale hypnale was observed mostly on ground (n=163) and occasionally was also found on the vegetation (small herbs and shrubs, n=3) during the monsoon. During the course of the study 3 individuals of *H. hypnale* were encountered on herbs and shrubs (unidentified) at an average height of up to 0.39 m from the ground. The associated flora and fauna of *H. hypnale* are listed in Appendix 1 and 2. Amongst the individuals encountered on the ground 65.03% were found on the ground beneath the leaf litter, whereas, 12.27% and 22.7% were found below the fallen tree trunk (logs) on the forest floor and on bare ground (without leaf litter) respectively. It was also observed that the individuals found on the bare ground were always closer to cover objects (thick leaf litter and logs). The average leaf litter thickness (depth) analysed for the individuals found below leaf litter was 88.7 ± 42.7 mm. During the post monsoon, winter and late summer *H. hypnale* were encountered in the cashew plantations within and adjoining the protected areas.

The average ambient temperature during post monsoon, winter and late summer in the forest area was 30.9 ± 0.65 °C and average humidity recorded was 76.6 ± 5.36%, whereas, the average leaf litter temperature was 30.48 ± 0.6 °C and average humidity recoded was 78.4 ± 4.72%. The average ambient temperature during post monsoon, winter and late summer in the cashew plantation was 29.72 ± 0.43 °C and average humidity recorded was 69.4 ± 10.13%, whereas, the average leaf litter temperature was 27.76 ± 1.53 °C and average humidity recorded was 74.4 ± 11.10%. The temperature of the leaf litter core was 1.96 ±1.32 °C lower than the ambient temperature whereas, the humidity was 5 ± 1.87% higher than ambient humidity as compared to the forest area where the leaf litter temperature was 0.42 ± 0.13 °C lower and humidity was 1.8 ± 0.83%, higher than the ambient temperature and humidity during the post monsoon and winter season. There was a significant difference between the ambient and leaf litter temperature ($F=6.69$, $df=1$, $p=0.03$) and humidity ($F=12.19$, $df=1$, $p=0.008$) in forest and cashew plantations.

Table 10: List of Forest/sub types present in the study locations

FOREST /FOREST SUB TYPE	SANCTUARY				
	MWS	BWS	BMWS and NP	NWS	CWS
1. West coast tropical evergreen	√		√	√	
2. Cane brakes	√		√	√	√
3. Wet bamboo brakes	√		√	√	√
4. Slightly moist teak forests	√		√	√	
5. Southern moist mixed deciduous forests		√	√	√	√
6. South Indian sub-tropical savannah woodland	√		√	√	√
7. Southern sub-tropical hill forest			√	√	√
8. Southern secondary moist mixed deciduous forest	√	√		√	√
9. West coast semi evergreen	√	√	√	√	√
10. Moist bamboo brakes	√		√		
11. Lateritic semi- evergreen forest	√		√		

Table 11: List of Forest/ Sub types preferred by the pit vipers

FOREST/FOREST SUB TYPES	SPECIES		
	T. malabaricus	*T. gramineus*	*H. hypnale*
1.West coast tropical evergreen	*	*	*
2. Cane brakes		*	*
3. Wet bamboo brakes		*	*
4. Slightly moist teak forest	*	*	*
5. Southern moist mixed deciduous forests	*	*	
6. South Indian sub-tropical savannah woodland	*	*	*
7. Southern sub-tropical hill forest	*	*	*
8.Southern secondary moist mixed deciduous forest	*	*	*
9. West coast semi evergreen	*	*	*
10. Moist bamboo brakes	*	*	*
11.Lateritic semi- evergreen forest	*	*	*

Table 12: The number of individuals of pit viper species found in different habitat type

Species	Forest	Edge	Open
T. malabaricus	79	11	0
T. gramineus	43	57	0
H. hypnale	73	93	0

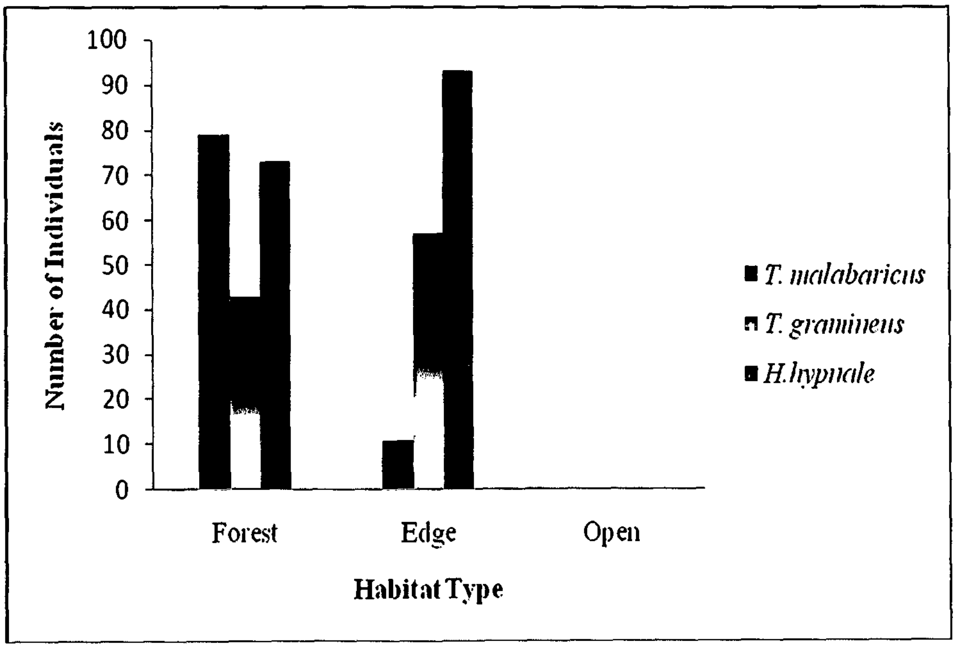


Figure 7: Graph showing the number of individuals of pit viper species found in different habitat type

Table 13: The number of individuals of *T. malabaricus* (male/female) found in different habitat type

T. malabaricus	**Forest**	**Edge**	**open**
Male	30	4	0
Female	49	7	0

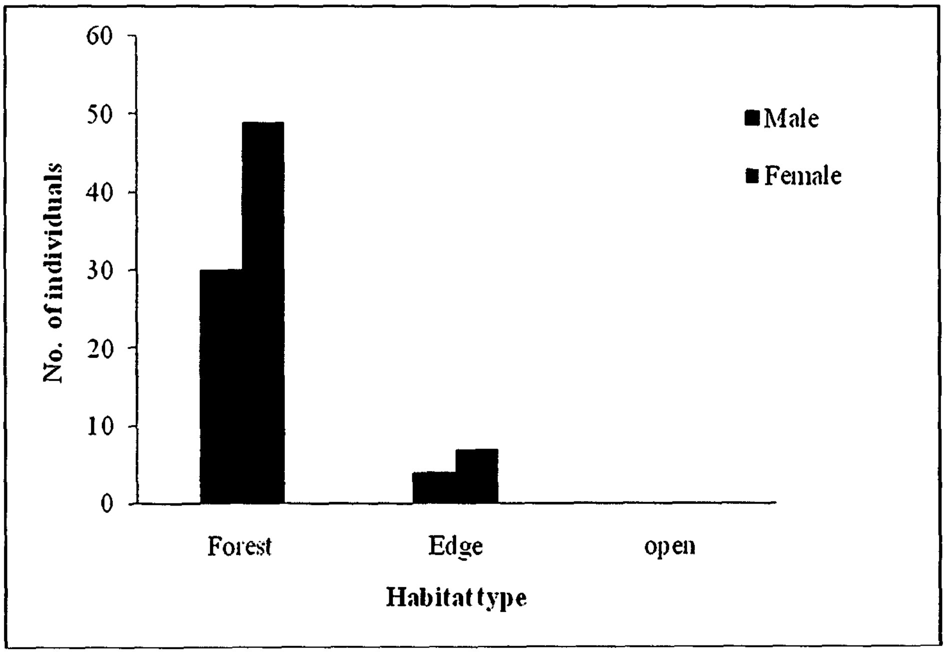


Figure 8: Graph showing the number of individuals of *T. malabaricus* (male/female) found in different habitat type

Table 14: The number of individuals of *T. gramineus* (male/female) found in different habitat type

T. gramineus	**Forest**	**Edge**	**open**
Male	16	31	0
Female	24	29	0

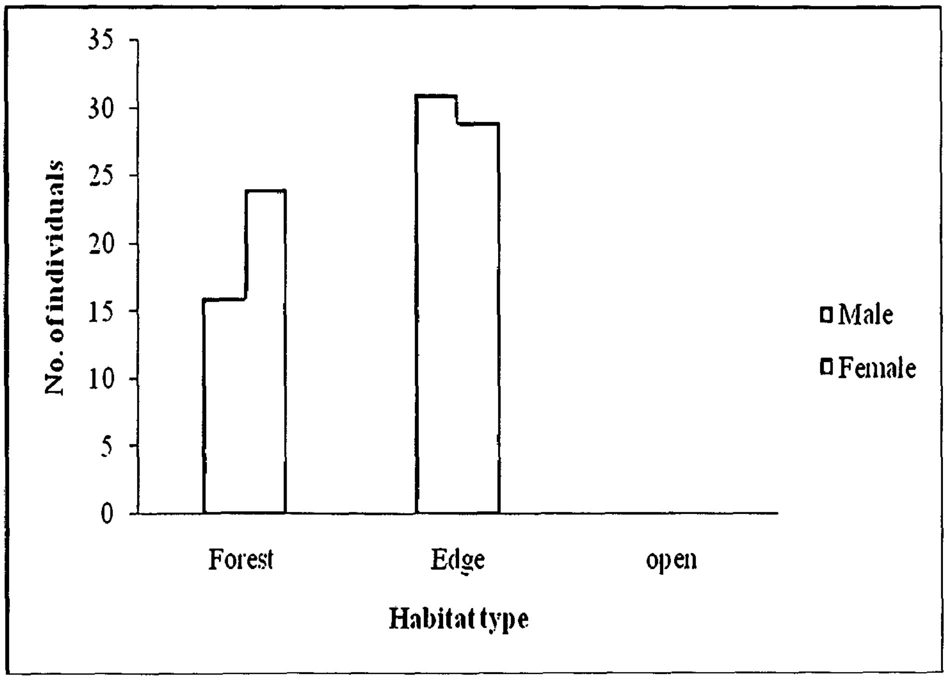


Figure 9: Graph showing the number of individuals of *T. gramineus* (male/female) found in different habitat type

Table 15: The number of individuals of *H. hypnale* (male/female) found in different habitat type

H. hypnale	Forest	Edge	open
Male	26	31	0
Female	47	61	0

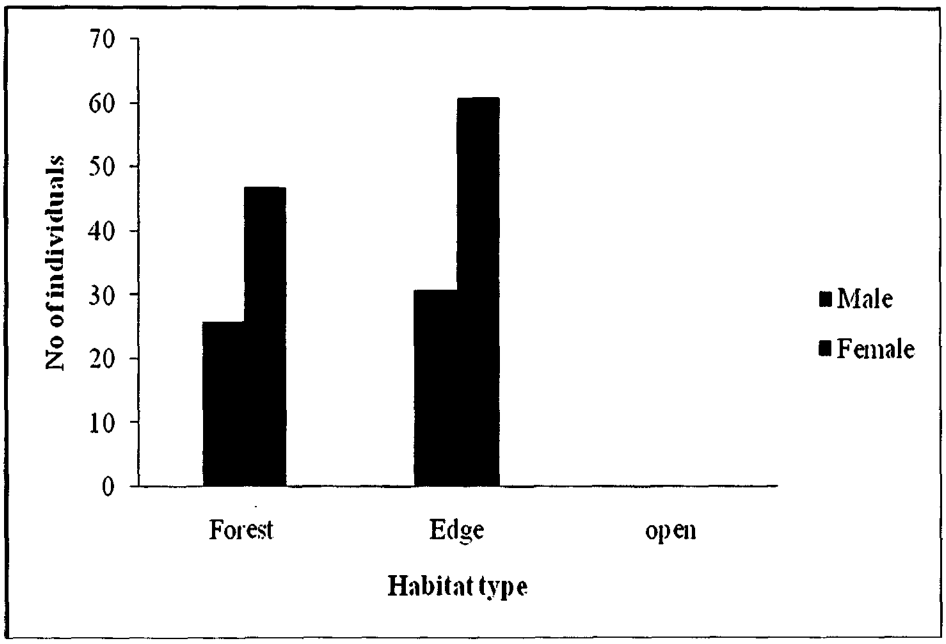


Figure 10: Graph showing the number of individuals of *H. hypnale* (male/female) found in different habitat type

Table 16: The number of individuals of *H. hypnale* found in forest and cashew plantations during different seasons

Area	Summer	Monsoon	Post Monsoon	Winter
Forest	31	55	17	11
Cashew Plantation	6	0	30	21

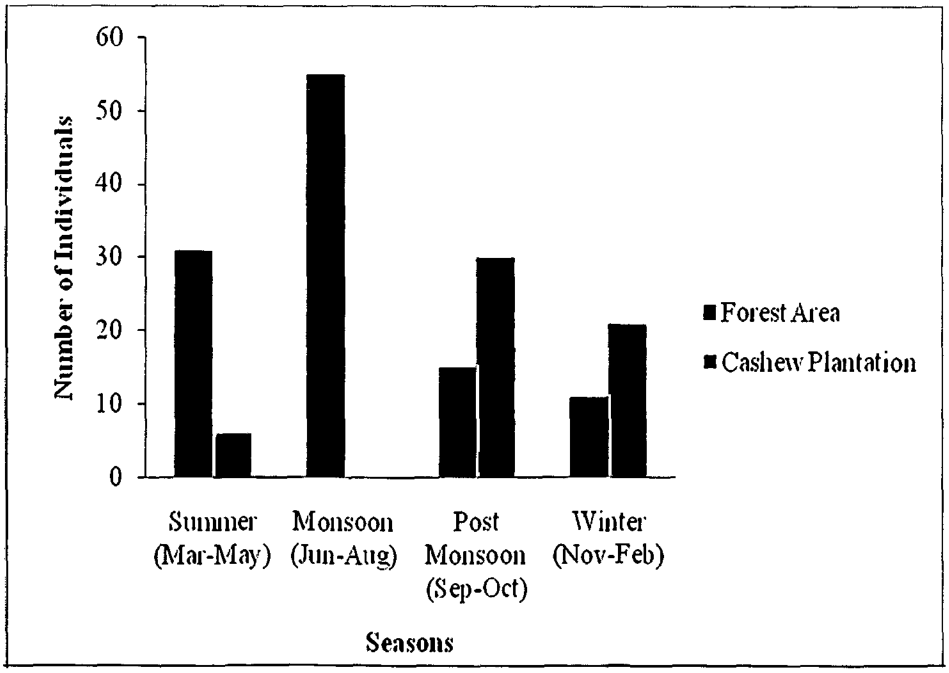


Figure 11: Graph showing the number of individuals of *H. hypnale* found in forest and cashew plantations during different seasons

Table 17: The number of individuals of *H. hypnale* (male/female) found in Forest and Cashew plantations

H. hypnale	Cashew Plantation	Forest
Male	10	49
Female	44	63

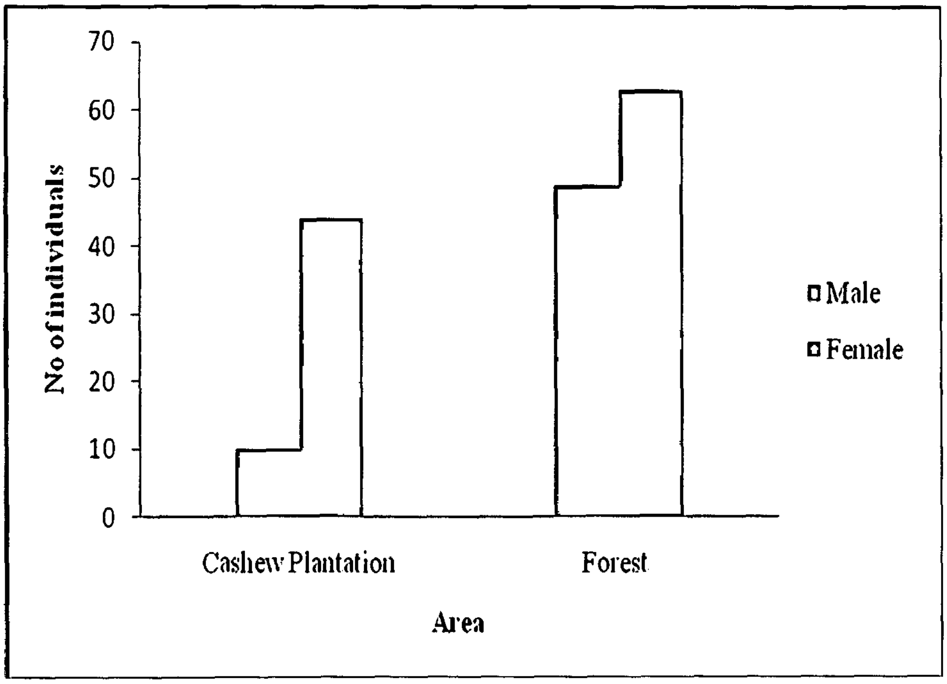


Figure 12: Graph showing the number of individuals of *H. hypnale* (male/female) found in Forest and Cashew plantations

Table 18: Range of temperature and humidity in different seasons

Seasons	Temperature °C	Humidity %
Summer	28 - 35	51 - 79
Monsoon	21 - 28	88 - 98
Winter	18 - 33	65 - 85

Table 19: The floral species utilized by *T. malabaricus* and *T. gramineus*

Floral species	*T. malabaricus*	*T. gramineus*
Bamboosa bambos		√
Calicopteris floribunda	√	√
Careya arborea	√	
Carvia callosa	√	√
Catunaregum spinarum	√	√
Dalbergia latifolia	√	√
Dendrocalamus strictus		√
Duranta species		√
Eupatorium odoratum	√	√
Grewia species (Unidentified)		√
Grewia tiliaefolia		√
H *~~hel~~icteris isora*	√	√
Leea indica	√	√
Melastoma malabatricum	√	
Mussaenda glabrata	√	√
Psychotria dalzelli	√	
Strychnos nuxvomica,		√
Tabernamonatana hyneana		√
Terminalia paniculata		√
Woodfordia fruticosa	√	√

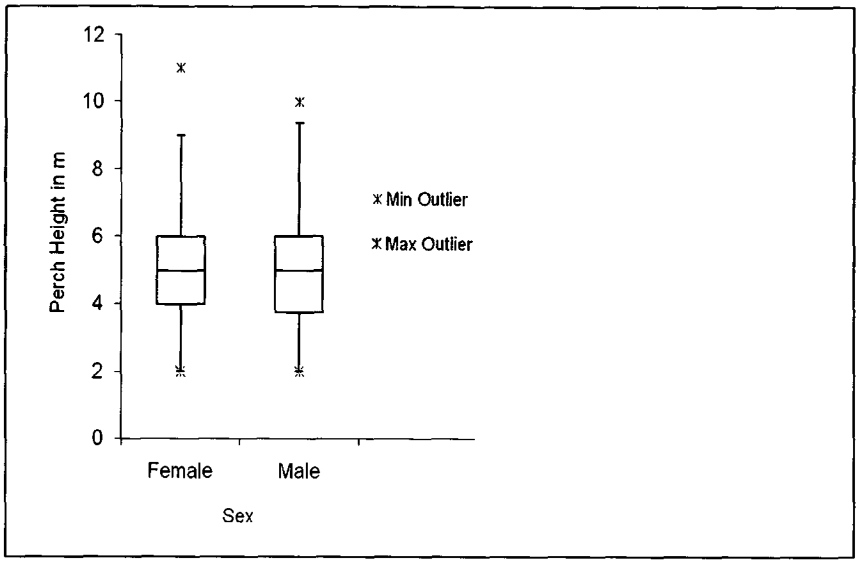


Figure 13: Graph showing the mean perch height attained by *T. malabaricus* (male/female). The box represents the 50% of the population, the horizontal line in the box represents the mean, the whiskers represent 75% of the remaing 50 % of the population and points represent the min amd max height attained by the individuals

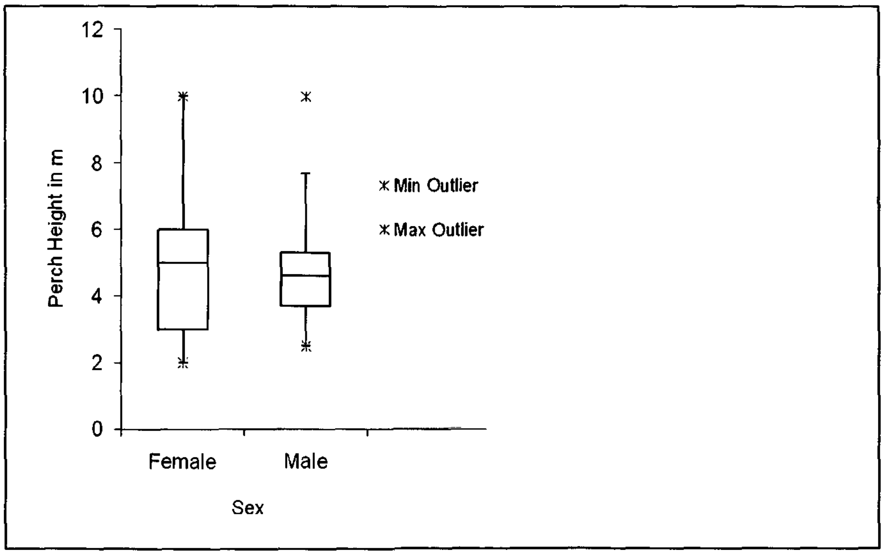


Figure 14: Graph showing the mean perch height attained by *T. gramineus* (male/female). The box represents the 50% of the population, the horizontal line in the box represents the mean, the whiskers represent 75% of the remaing 50 % of the population and points represent the min amd max height attained by the individuals

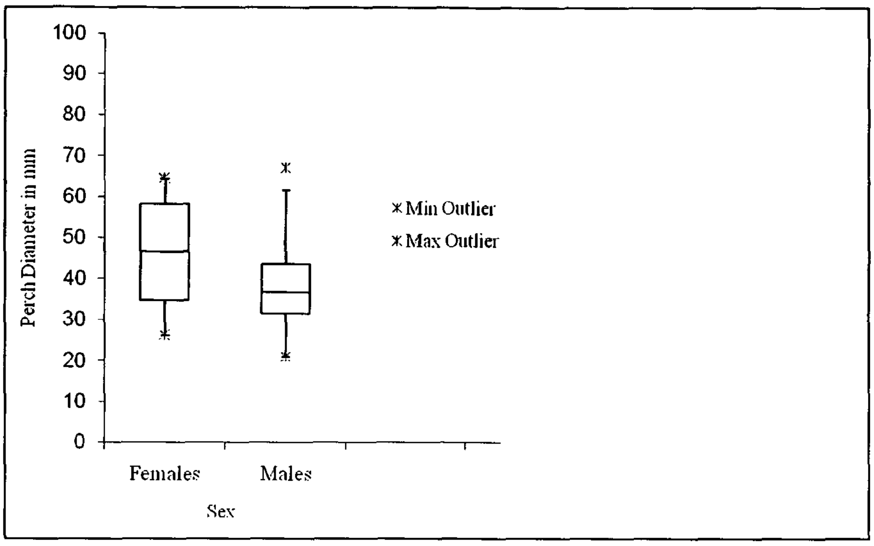


Figure 15: Graph showing the mean perch diameter utilized by *T. malabaricus* (male/female). The box represents the 50% of the population, the horizontal line in the box represents the mean, the whiskers represent 75% of the remaing 50 % of the population and points represent the min amd max perch diameter utilized by the individuals

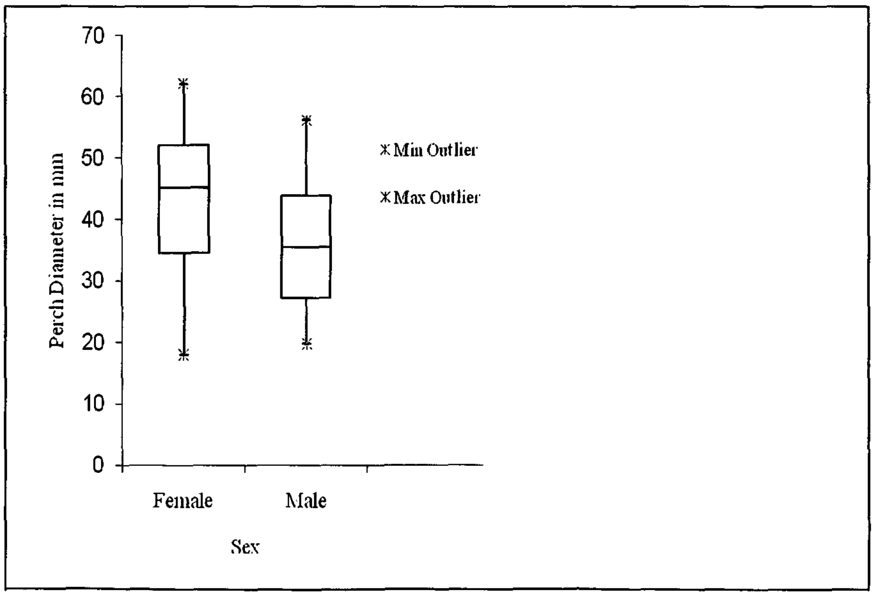


Figure16: Graph showing the mean perch diameter utilized by *T. gramineus* (male/female). The box represents the 50% of the population, the horizontal line in the box represents the mean, the whiskers represent 75% of the remaing 50 % of the population and points represent the min amd max perch diameter utilized by the individuals

Table 20: The number of individuals of arboreal pit viper species occupying different regions on the branch

Species	Distal	Middle	Apical
T. malabaricus	9	59	26
T. gramineus	54	17	6

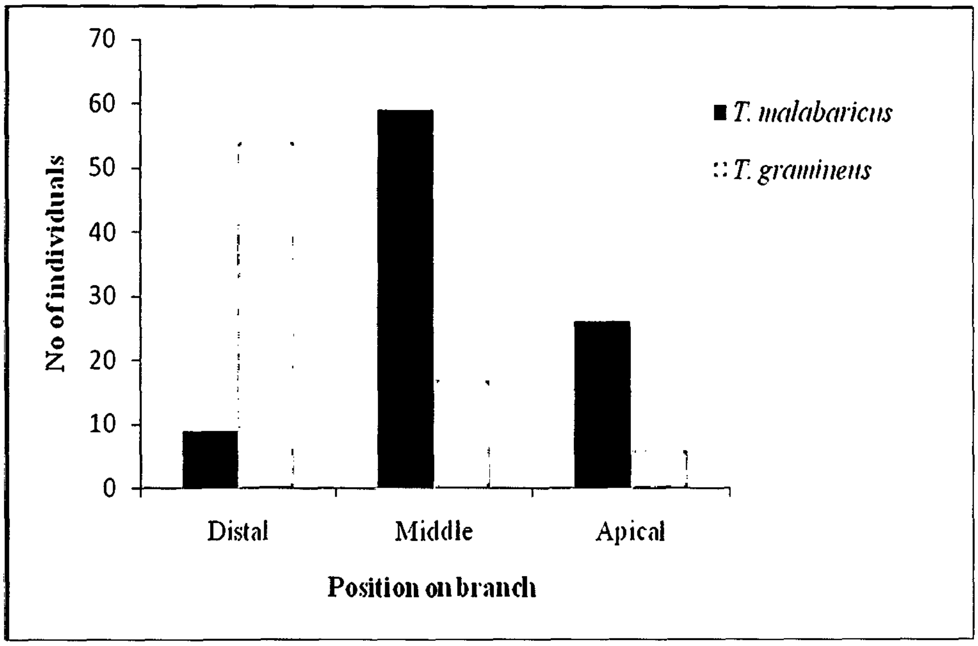


Figure 17: Graph showing the number of individuals of arboreal pit viper species occupying different regions on the branch

Table 21: The number of individuals of *T. malabaricus* (male/female) occupying different regions on the branch

Sex	Apical	Distal	Middle
Male	17	4	7
Female	37	2	10

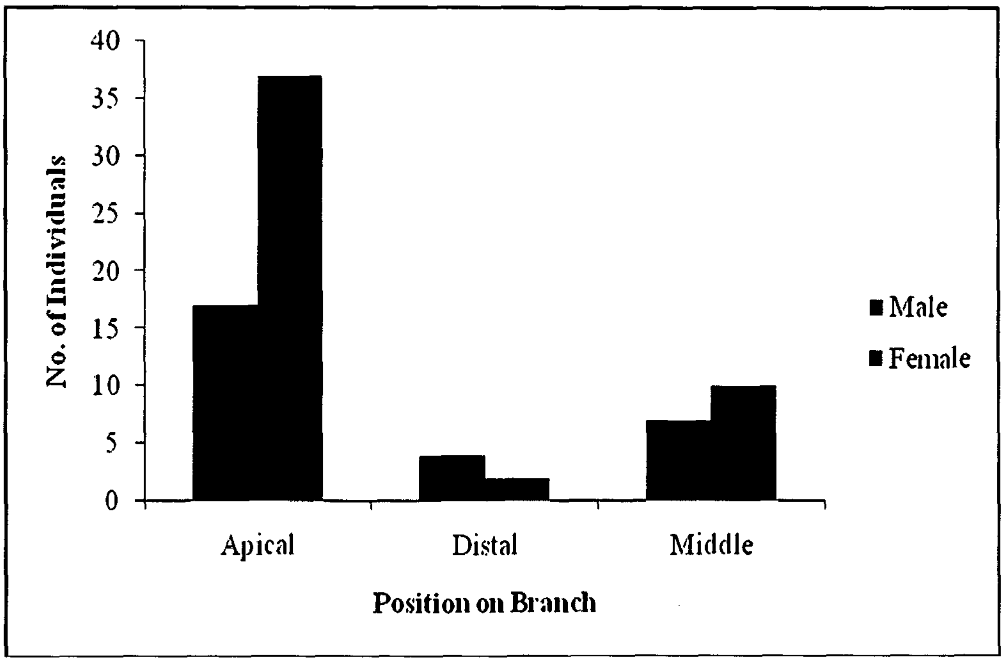


Figure 18: Graph showing the number of individuals of *T. malabaricus* occupying different regions on the branch

Table 22: The number of individuals of *T. gramineus* (male/female) occupying different regions on the branch

Sex	Apical	Distal	Middle
Male	11	7	24
Female	19	2	31

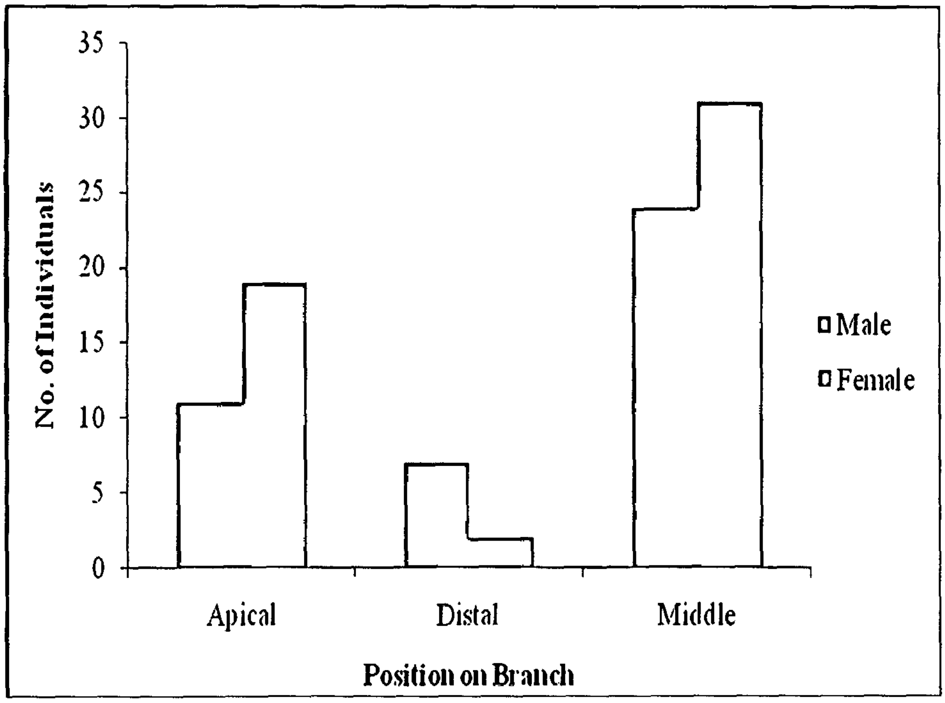


Figure 19: Graph showing the number of individuals of *T. gramineus* occupying different regions on the branch

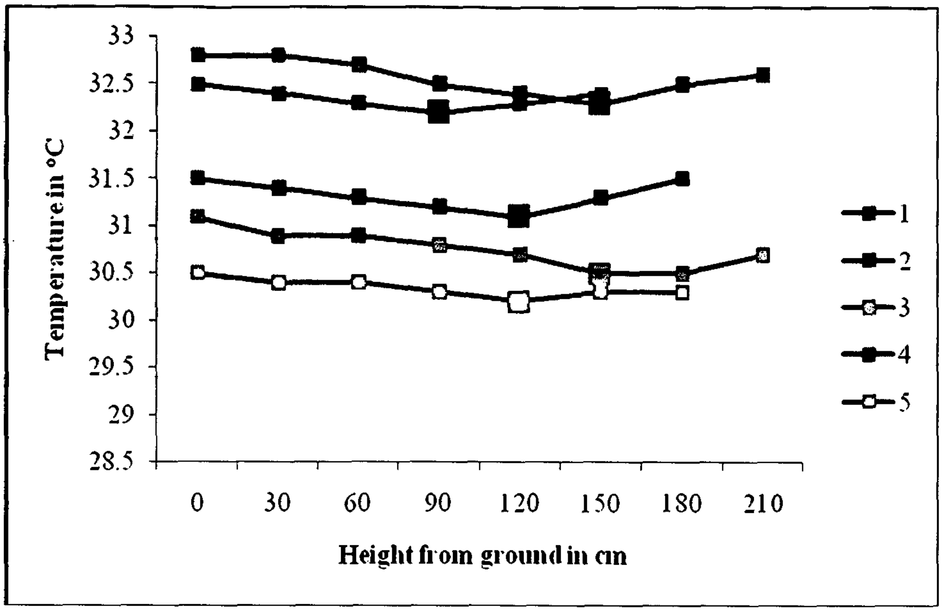


Figure 20: Graph showing the location of arboreal pit viper and the shaded ambient temperature at different heights from the ground during summer (the larger bullets indicates the height from the ground where the pit viper was located)

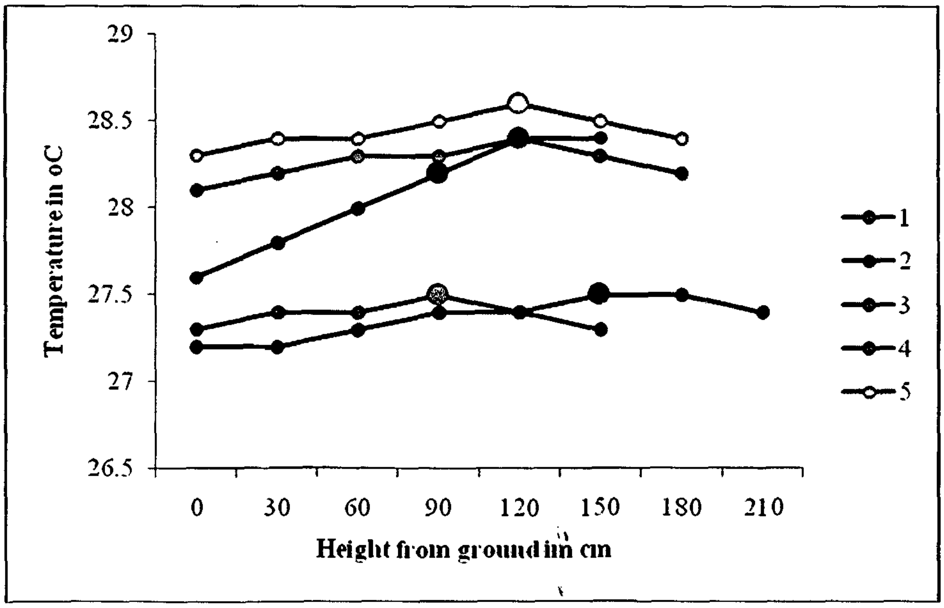


Figure 21: Graph showing the location of arboreal pit viper and the shaded ambient temperature at different heights from the ground during monsoon (the larger bullets indicates the height from the ground where the pit viper was located)

Colour

All the three species exhibited colour change. The colour patterns varied during different seasons i.e. during dry season (summer and winter) and wet season (monsoon). The substratum used also influenced the colour change. These colour differences are consistent with the differences in frequency of habitat and microhabitat use, *T. malabaricus* and *T. gramineus* being camouflaged against the background of bark of the tree and green foliage in the forest respectively, whereas, *H. hypnale* is camouflaged against the terrestrial background in the leaf litter and ground. However, no sexual dimorphism in colour was observed in all the three species.

Colour variation in *T. malabaricus:*

Majority of the *T. malabaricus* (n=68) encountered were greenish or olive above with more or less distinct brown or blackish spots separated from one another or confluent in zig -zag form; usually an irregular series of yellow spots were present along the flanks; lower part was pale green or yellow and a black temporal streak which were more or less distinct; tail was black and yellow in colour.

In the dry season four distinct colour patterns in *T. malabaricus* were observed. Five individuals exhibited typically light brown back with prominent dark brown spots that joined to form a zig- zag pattern. The zig –zag pattern was missing on the head. Dark streaks were present behind the eyes. Flanks were pale bluish green intermixed with pale brown; underside was white in colour without any markings. Tail was black and faint yellow in colour with predominantly dark form. The upper lip was faint bluish green in colour while the lower lip was dull white in colour (Plate: 4a). Three *T. malabaricus* exhibited a typical dull brown colour with prominent reddish brown and faint yellowish brown spots that joined to form a bold zig- zag pattern. Similar markings were present on the head; dark brown streaks were present behind the eyes. Flanks were coarsely dappled with buff underside interrupted with faint yellow and buff with scattered white spots on the edges. Tail was black and faint yellow with predominant brown form. The upper and lower lips were yellowish and buff coloured (Plate: 4b).

One individual exhibited typically dark brown colour with prominent moss green and white bands that forms zig- zag pattern, resembling the moss and lichens on the tree branch. Eyes were not distinct from the body colour. Flanks, underside, head and tail with dark brown, moss green and white blotches; lips were not distinct from the body colour (Plate: 4c). Four *T. malabaricus* exhibited a typical chocolate brown back with bright yellow and light green blotches that forms a zig – zag pattern throughout the body. There were scattered yellow spots along the sides. Dark chocolate brown streaks were present behind the eyes. Underside was pale green with scattered yellow or greenish white markings. Tail was with dark black and bright yellow spots (Plate: 4d).

In the wet season three distinct colour patterns were observed in *T. malabaricus*. Three *T. malabaricus* exhibited a typical pale green colour with dark brown intermixed with black and yellow blotches that forms a zig- zag pattern throughout the length of the body; flanks were pale green in colour; underside was pale green in colour and dark brown streaks were present behind the eyes. Tail had dark brown and bright yellow spots

(Plate: 5a). Four *T. malabaricus* exhibited bright yellow body colour with dark brown and white blotches intermixed to form the zig – zag pattern on the dorsal side. The zig – zag pattern was not continuous throughout the length of the body and was interrupted by yellow blotches. Underside and flanks were yellow in colour. Tail with dark black and bright yellow spots (Plate: 5b). Two individuals exhibited bluish green body colour with chocolate brown and yellow blotches which joined to form zig zag pattern on the dorsal side of the body. Dark brown streaks were present behind the eyes. Flanks were bluish green in colour with pale yellow on ventro - lateral side. Underside was pale yellowish green. Tail had prominent black and yellow spots (Plate: 5c).

Colour variation in *T. gramineus*:

No much colour variation in *T. gramineus* was observed during the present study. However it exhibited slight change in colour during dry and wet season and the colour change was basically related to the type of substrate used i. e. depending on the colour of the vegetation. During wet season it exhibited bright colour pattern (Plate: 6 a and b), whereas, during dry season the colour pattern was dull or faint (Plate: 7). It mostly exhibited green or yellowish-green above, uniform or with occasional small dark brown spots produced by an extension of the colour of the interstitial skin on to the base of the scales and had whitish or greenish underside. The green colour of the dorsum extended on to the outer edge of the ventrals, and the pale colour of the ventrals on to the outer dorsal scales, the resulting pattern being a broken and uneven line along the flanks. The lips were whitish and dark temporal streaks behind the eyes were absent.

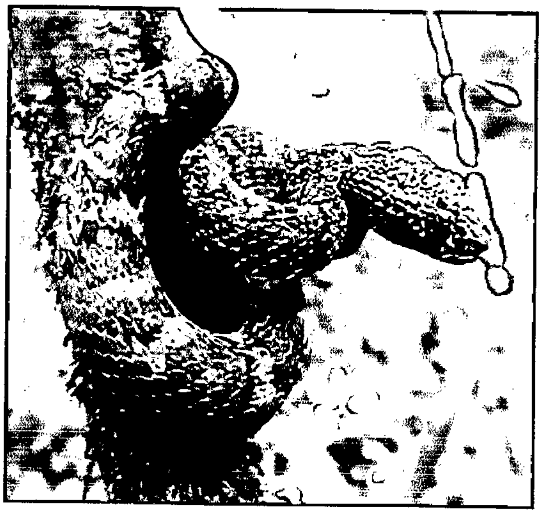
Colour variation in *H. hypnale:*

Hypnale hypnale exhibited varied colour patterns, however, it was observed that the change in colour was related to the colour of the substrate used and it did not vary with seasons. It was mostly yellowish tan or reddish brown or dull brownish above, heavily powdered and mottled with brown. There were a series of large, dark, angular or oblong spots on each side of the midline, sometimes alternating with those of the other side; sometimes series of lateral spots were present. The underside was grayish, yellowish or brownish, sometimes more or less heavily spotted with dark brown or black spots. Top of the head was usually dark brown and a dark post ocular stripe with a light one above it was present. Pair of longitudinal dark stripes on the nape was present; tip of the tail was often yellowish or reddish or brownish in colour (Plate: 8 a-f).

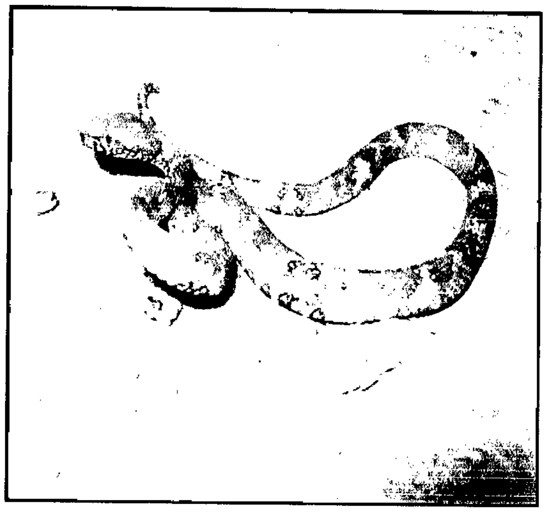
Juveniles were mostly dark grayish or brownish above with series of small dark, angular black spots on each side of the midline alternating with those of the other side. Underside was light ash- grey with dark black spots. A dark post ocular stripe was present and tip of the tail was yellowish in colour (Plate: 9 a and b).

(a)

(b)

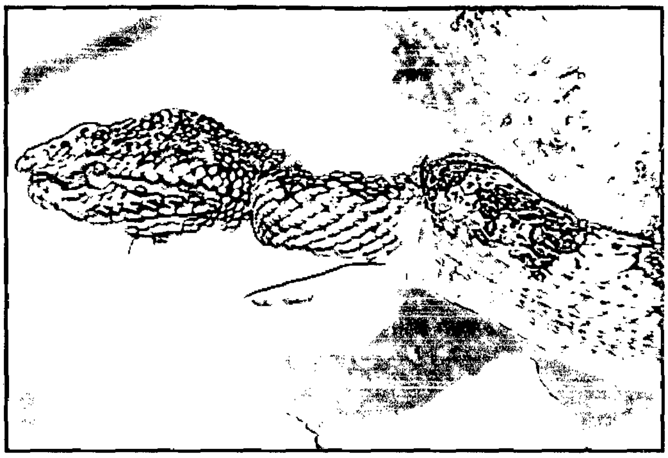


(c)

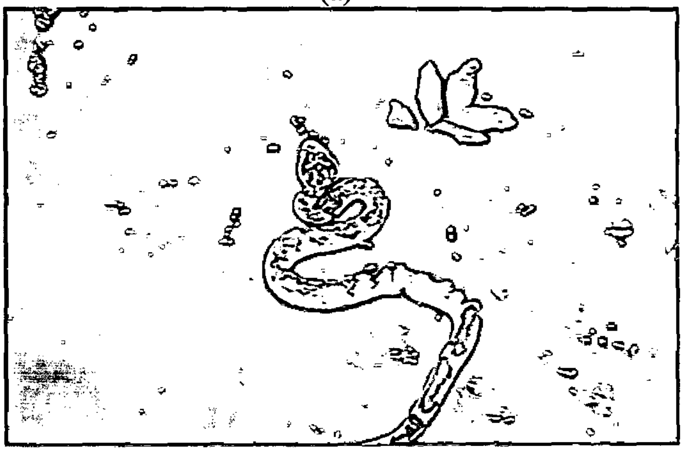


(d)

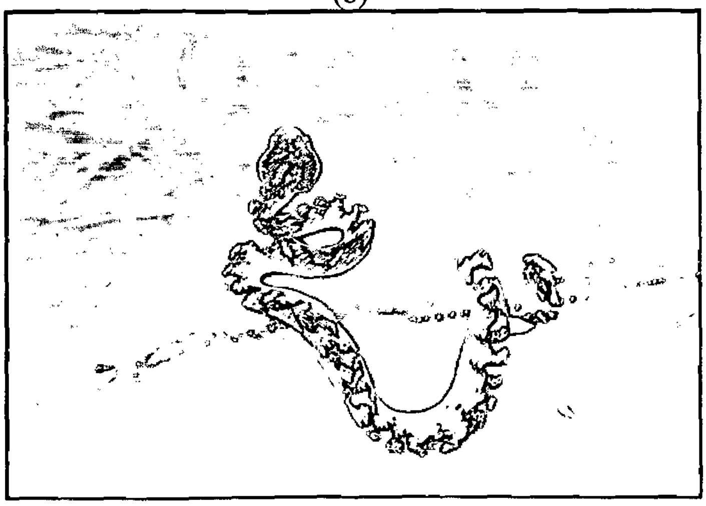
Plate 4 (a-d): Colour patterns exhibited by *T. malabaricus* during dry season



(a)



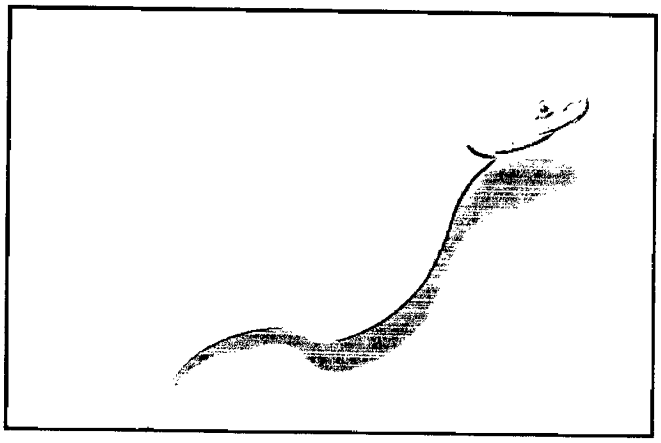
(b)



(c)

Plate 5 (a-c): Colour patterns exhibited by *T. malabaricus* during wet season

(a)



(b)

Plate 6 (a and b): Colour patterns exhibited by *T. gramineus* during wet season

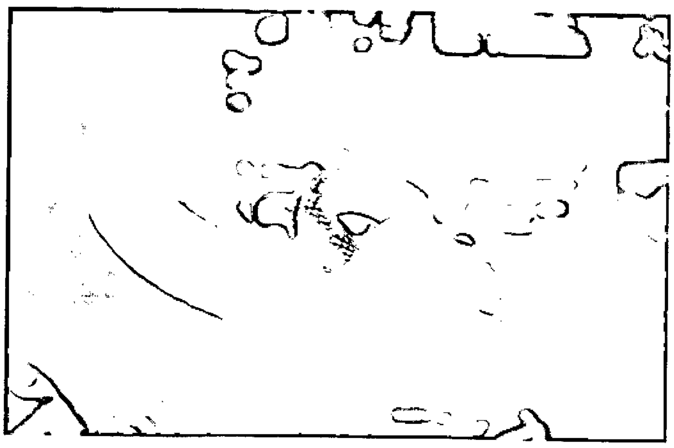


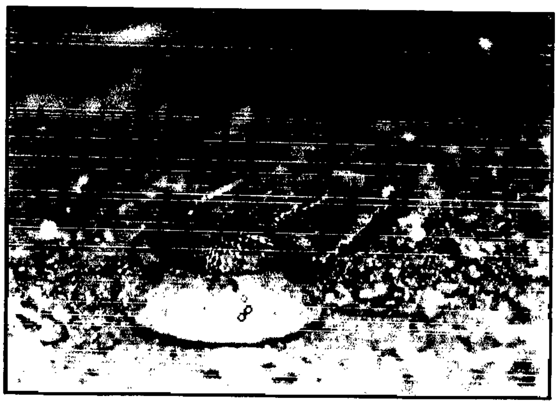
Plate 7: Colour patterns exhibited by *T. gramineus* during dry season

(a)

(b)

(c)

(d)



(e)

(f)

Plate 8 (a-f) : Colour patterns exhibited by adult *H. hypnale*

(a)

(b)

Plate 9 (a and b): Colour patterns exhibited by juvenile *H. hypnale*.

Reproduction

Morphological data for 90 *T. malabaricus* (34 males and 56 females), 100 *T. gramineus* (47 males and 53 females), 166 adult *H. hypnale* (59 males and 107 females) and 18 neonates of *H. hypnale* were obtained. Sex ratios were heavily female-biased among all the three species. The male: female ratio for all the three species in different study area is listed in table: 23.

Sexual dimorphism in body size (adults):

The average snout vent length (SVL) of all the three species is provided in table 24. In mature males of *T. malabaricus* the SVL averaged 384 ± 7.9 mm (300 to 450mm), mature females averaged 456 ± 1.3 mm in SVL (210 to 650 mm). The SVL in mature males of *T. gramineus* averaged 474 ± 6.9 mm (370 to 600 mm), mature females averaged 536 ± 9.4 mm in SVL (370 to 670 mm). The SVL in mature males of *H. hypnale* averaged 307 ± 3.1 mm (270 to 400 mm), mature females averaged 392 ± 3.1 mm in SVL (280 to 440 mm) (Table: 24, Figure: 22). One-way ANOVA showed that SVL varied significantly between male and female of each species when tested separately [*T. malabaricus* ($F=7.34$, $df=1$, $p= 0.008$), *T. gramineus* ($F=9.28$, $df= 1$, $p= 0.004$) and *H. hypnale* ($F= 8.71$, $df= 1$, $p=0.009$)]. However, it varied insignificantly between species ($p>0.05$).

The average caudal length (CL) for all the three species is provided in table 25. In mature males of *T. malabaricus* the CL averaged 86 ± 1.9 mm (40 to 99 mm), mature females averaged 110 ± 1.5 mm in CL (80 to 130 mm). The CL in mature males of *T. gramineus* averaged 101.6 ± 1.2 mm (80 to 120 mm), mature females averaged 117 ± 1.7 mm in CL (84 to 131 mm). The CL in mature males of *H. hypnale* averaged 46.4 ± 0.6 mm (40 to 62 mm), mature females averaged 54.9 ± 0.5 mm in CL (40 to 70 mm) (Table 25, Figure 23). One-way ANOVA showed that CL varied significantly between male and female of each species when tested separately [*T. malabaricus* (F=20.75, df=1, p= 0.0001), *T. gramineus* (F=17.03, df= 1, p= 0.0001) and *H. hypnale* (F= 15.61, df= 1, p=0.0004)]. However, it varied insignificantly between species (p>0.05).

The average head length (HDL) in all the three species of pit vipers is provided in table 26. In mature males of *T. malabaricus* the HDL averaged 23.6 ± 0.63 mm (18 to 32 mm); mature females averaged 27.6 ± 0.58 mm in HDL (19 to 38 mm). The HDL in mature males of *T. gramineus* averaged 21.9 ± 0.42 mm (17 to 28 mm), mature females averaged 25.9 ± 0.58 mm in HDL (17 to 31 mm). The HDL in mature males of *H. hypnale* averaged 17.4 ± 0.16mm (14 to 20 mm), mature females averaged 21.6 ± 0.27 mm in HDL (13 to 30 mm) (Table 26, Figure 24). One-way ANOVA showed that HDL varied significantly between male and female of each species when tested separately [*T. malabaricus* (F=4.63, df=1, p= 0.03), *T. gramineus* (F=14.54, df= 1, p= 0.0004) and *H. hypnale* (F= 16.82, df= 1, p=0.0004)]. However, it varied insignificantly between species (p>0.05).

The average head width (HDW) of all the three species of pit vipers is provided in table 27. In mature males of *T. malabaricus* the HDW averaged 18.7 ± 0.6 mm (11 to 26 mm), mature females averaged 22.7 ± 0.5 mm in HDW (12 to 32 mm). The HDW in mature males of *T. gramineus* averaged 18 ± 0.3 mm (12 to 23 mm), mature females averaged 21.9 ± 0.5 mm in HDW (12 to 29 mm). The HDW in mature males of *H. hypnale* averaged 12.2 ± 0.2 mm (10 to 15 mm), mature females averaged 16.3 ± 0.2 mm in HDW (11 to 25 mm) (Table: 27, Figure: 25). One-way ANOVA showed that HDW varied significantly between male and female of each species when tested separately [*T. malabaricus* (F=5.23, df=1, p= 0.02), *T. gramineus* (F=13.71, df= 1, p= 0.006) and *H. hypnale* (F= 11, df= 1, p=0.003)]. However, it varied insignificantly between species (p>0.05).

The average ventral scale (VS) count in all the three species of pit vipers is provided in table 28.In mature males of *T. malabaricus* the VS averaged 148.3 ± 1.58 mm and ranged from 143 to 157 mm), mature females averaged 150.9 ± 0.85 mm in VS (136 to 159 mm). The VS in mature males of *T. gramineus* averaged 164 ± 1.58 mm (145 to 185 mm), mature females averaged 170.6 ± 0.57 mm in VS (158 to 177 mm). The VS in mature males of *H. hypnale* averaged 144.3 ± 0.64 mm (135 to 155 mm), mature females averaged 159 ± 0.74 mm in VS (141 to 171 mm) (Table: 28, Figure: 26). One-way ANOVA showed that VS varied significantly between male and female of each species when tested separately [*T. malabaricus* (F=7.25, df=1, p= 0.017), *T. gramineus* (F=6.31, df= 1, p= 0.016) and *H. hypnale* (F= 16.75, df= 1, p=0.001)]. However, it varied insignificantly between species (p>0.05).

The average caudal scale (CS) in all the three species of pit vipers is provided in table 29. In mature males of *T. malabaricus* the CS averaged 52.34 ± 0.54 mm (45 to 60 mature males of *T. gramineus* averaged 18 ± 0.3 mm (12 to 23 mm), mature females averaged 21.9 ± 0.5 mm in HDW (12 to 29 mm). The HDW in mature males of *H. hypnale* averaged 12.2 ± 0.2 mm (10 to 15 mm), mature females averaged 16.3 ± 0.2 mm in HDW (11 to 25 mm) (Table: 27, Figure: 25). One-way ANOVA showed that HDW varied significantly between male and female of each species when tested separately [*T. malabaricus* (p= 0.02, df=1, F=5.23), *T. gramineus* (p= 0.006, df= 1, F=13.71) and *H. hypnale* (p=0.003, df= 1, F= 11)]. However, it varied insignificantly between species (p>0.05).

The average ventral scale (VS) count in all the three species of pit vipers is provided in table 28.In mature males of *T. malabaricus* the VS averaged 148.3 ± 1.58 mm and ranged from 143 to 157 mm), mature females averaged 150.9 ± 0.85 mm in VS (136 to 159 mm). The VS in mature males of *T. gramineus* averaged 164 ± 1.58 mm (145 to 185 mm), mature females averaged 170.6 ± 0.57 mm in VS (158 to 177 mm). The VS in mature males of *H. hypnale* averaged 144.3 ± 0.64 mm (135 to 155 mm), mature females averaged 159 ± 0.74 mm in VS (141 to 171 mm) (Table: 28, Figure: 26). One-way ANOVA showed that VS varied significantly between male and female of each species when tested separately [*T. malabaricus* (p= 0.017, df=1, F=7.25), *T. gramineus* (p= 0.016, df= 1, F=6.31) and *H. hypnale* (p=0.001, df= 1, F= 16.75)]. However, it varied insignificantly between species (p>0.05).

The average caudal scale (CS) in all the three species of pit vipers is provided in table 29. In mature males of *T. malabaricus* the CS averaged 52.34 ± 0.54 mm (45 to 60 mm), mature females averaged 50.5 ± 0.41 mm in CS (43 to 55 mm). The CS in mature males of *T. gramineus* averaged 61.38 ± 0.87 mm (52 to 72 mm), mature females averaged 60.37 ± 0.39 mm in CS (56 to 69 mm). The CS in mature males of *H. hypnale* averaged 37.67 ± 0.49 mm (31 to 46 mm), mature females averaged 45.11 ± 0.40 mm in CS (32 to 55 mm) (Table: 29, Figure: 27). One-way ANOVA showed that VS varied significantly between male and female of each species when tested separately [*T. malabaricus* ($F=5.94$, $df=1$, $p= 0.024$), *T. gramineus* ($F=5.14$, $df= 1$, $p= 0.029$) and *H. hypnale* ($F= 21.86$, $df= 1$, $p=0.0001$)]. However, it varied insignificantly between species ($p>0.05$).

In mature males of *T. malabaricus* (n=25) the body mass averaged 39.35 ± 1.63 gm (24 to 52.1 gm), mature females averaged 46.19 ± 1.88 gm in weight (30.1 to 62.1 gm). The weight of mature males of *T. gramineus* averaged 36.37 ± 1.33 gm (23 to 53 gm), mature females averaged 42.71 ± 1.72 gm in weight (25 to 60 gm). The body mass in mature males of *H. hypnale* averaged 14.16 ± 0.47 gm (8 to 20 gm), mature females averaged 35.94 ± 1.04 gm body mass (20 to 48 gm). One-way ANOVA showed that the body mass varied significantly between male and female of each species when tested separately [*T. malabaricus* ($F=7.49$, $df=1$, $p= 0.008$), *T. gramineus* ($F=8.47$, $df= 1$, $p= 0.004$) and *H. hypnale* ($F= 26.43$, $df= 1$, $p=0.0002$)]. However, it varied insignificantly between species ($p>0.05$). There was a positive correlation between body mass and total length when tested for males ($r =0.482$, $p<0.01$) and females ($r= 0.460$, $p=<0.01$) of *T. malabaricus*. *Trimeresurus gramineus* also showed a positive correlation between body mass and total length when tested for males ($r =0.373$, $p<0.05$) and females ($r= 0.622$,

$p<0.001$) .Similarly *H. hypnale* also showed a positive correlation between body mass and total length when tested for males ($r = 0.56$, $p<0.001$) and females ($r = 0.167$, $p>0.05$).

Sexual dimorphism in body size (neonates):

No juveniles were encountered during this study. No gravid females of *T. malabaricus* and *T. gramineus* were encountered during the present study. Two gravid females of *H. hypnale* were collected and maintained in captivity. The total length of the females was 412 and 477 mm and weighed 70 and 74 gm respectively. One of them, which was collected on 19th January 2009 littered on 19th April 2009 after a period three months of gestation in captivity. The other female which was collected on 6th March 2009 littered on 16th May 2009after a period of 40 days of gestation in captivity. Both had litter size of nine each with a sex ratio of 5 females: 4 males and 6 females: 3 males respectively. Three female mortalities were reported from the litter of the first female. The gravid females killed in cashew plantations contained seven fertilized eggs each. There was a positive correlation between body length and litter size ($r=0.098$, $p<0.001$, $n=4$).

The SVL of the neonates averaged 108.86 ± 0.62 mm (103 to 114 mm), CL averaged 19.7 ± 0.62 mm (16 to 24 mm). The HDL and HDW averaged 9.88 ± 0.23 mm (8 to 11 mm) and 6 ± 0.28 mm (4 to 8 mm) respectively, whereas, the body mass averaged 2 ± 0.01 gm (1.8 to 2.1 gm). The SVL, CL, HDW, HDL and body mass for male and female neonates are provided in table: 30. One-way ANOVA showed significant difference between SVL ($f=8.6$, $df=1$, $p=0.01$), CL ($f=49$, $df=1$, $p=0.0004$), HDL (f=21, df=1, p=0.003) and HDW (f=33.33, df=1, p=0.0004) of male and female neonates.

Table 23: male: female ratio for all the three species in different study area

Species	MWS	BMWS	NWS	CWS	BWS
T. malabaricus	0.68	0.75	0.44	0.55	0
T. gramineus	0.75	0.5	1.11	1.42	0.37
H. hypnale	0.69	0.56	0.63	0.46	0

Table 24: Average SVL (SE) in pit viper species

Sex	*T. malabaricus*	*T. gramineus*	*H. hypnale*
Male	384.4 (7.9)	473.9 (6.9)	307 (3.1)
Female	456 (13)	536 (9.4)	391.6 (3.1)

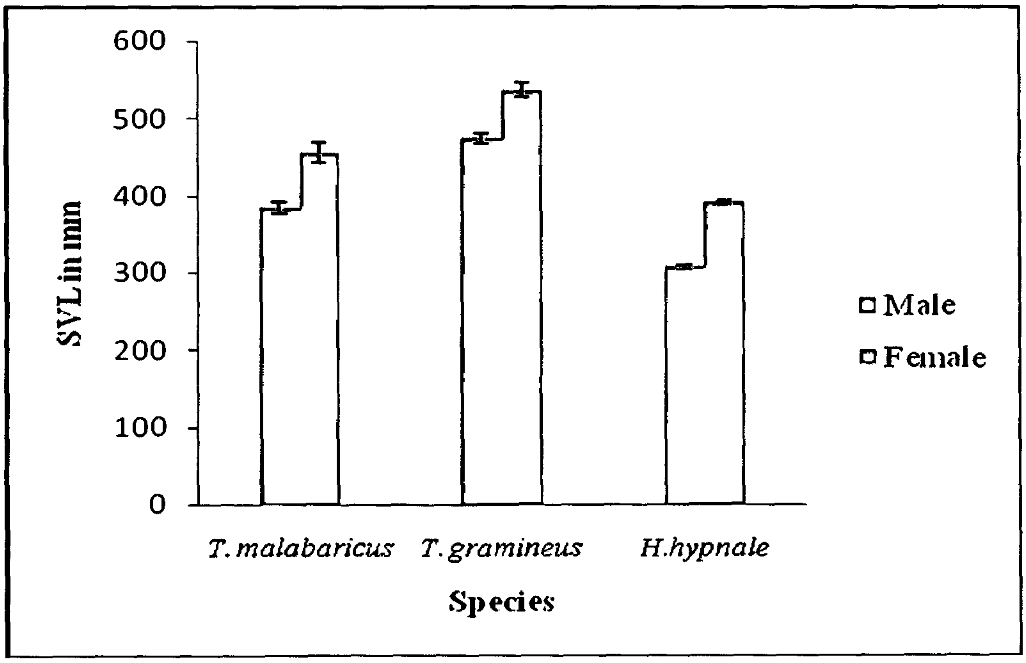


Figure 22: Graph showing average SVL (SE) in pit viper species

Table 25: Average CL (SE) in pit viper species

Sex	*T. malabaricus*	*T. gramineus*	*H. hypnale*
Male	86.8 (1.9)	101.6 (1.2)	46.4 (0.5)
Female	110.5 (1.5)	117 (1.7)	54.9 (0.5)

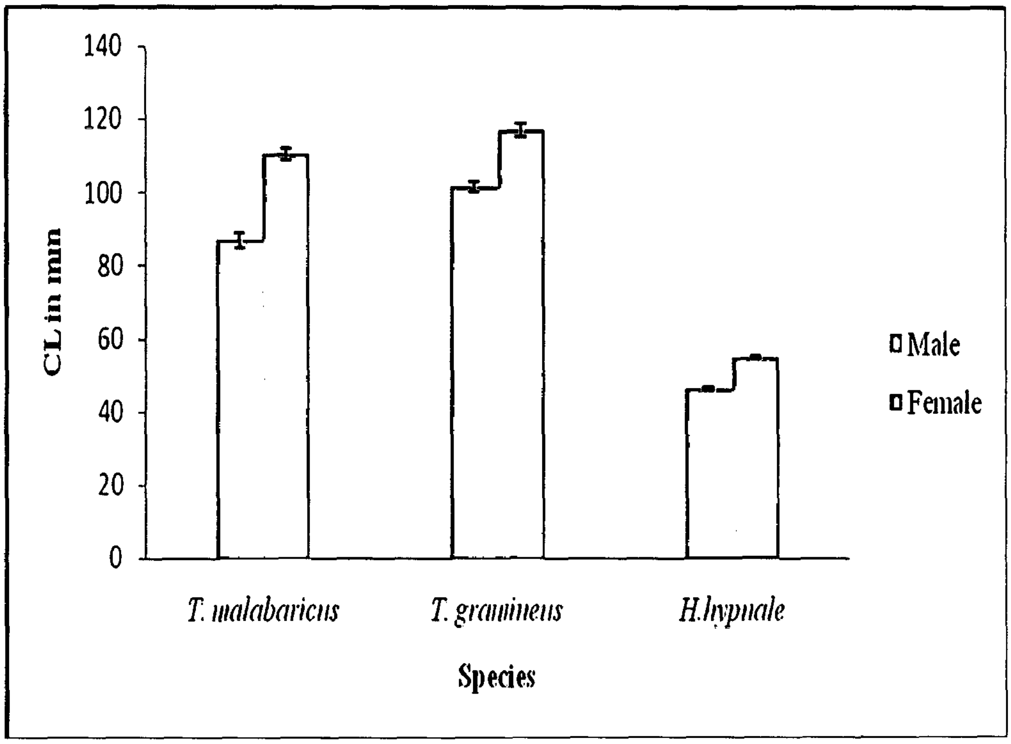


Figure 23: Graph showing average CL (SE) in pit viper species

Table 26: Average HDL (SE) in pit viper species

Sex	*T. malabaricus*	*T. gramineus*	*H. hypnale*
Male	23.6 (0.6)	21.9 (0.4)	17.4 (0.1)
Female	27.6 (0.5)	25.9 (0.5)	21.6 (0.2)

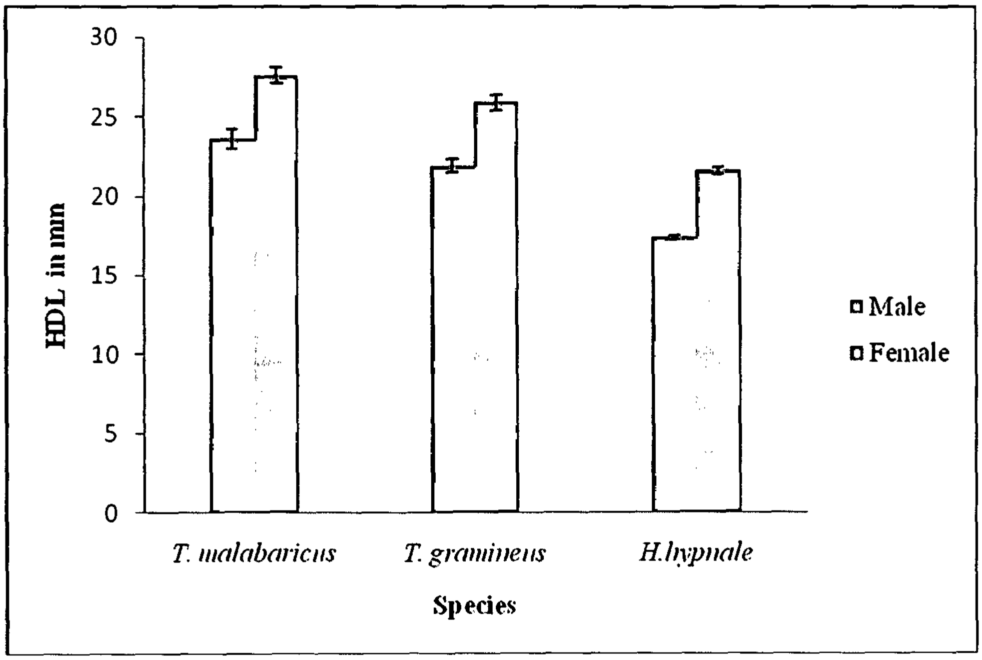


Figure 24: Graph showing average HDL (SE) in pit viper species

Table 27: Average HDW (SE) in pit viper species

Sex	*T. malabaricus*	*T. gramineus*	*H. hypnale*
Male	18.7 (0.6)	18 (0.3)	12.2 (0.2)
Female	22.7 (0.5)	21.9 (0.5)	16.3 (0.2)

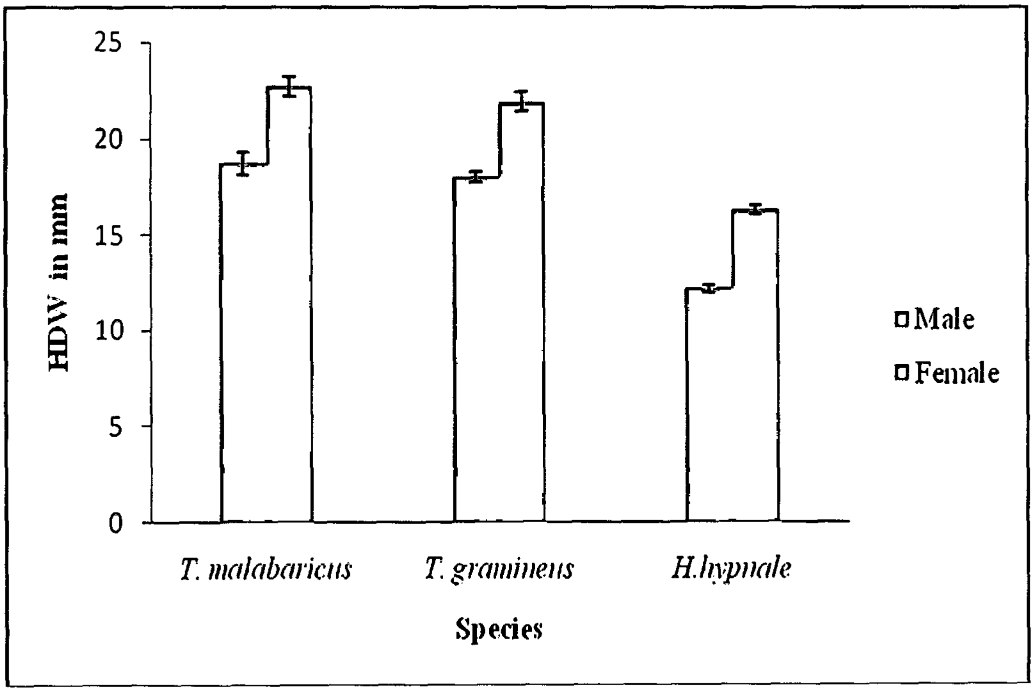


Figure 25: Graph showing average HDW (SE) in pit viper species

Table 28: Average VS (SE) in pit viper species

Sex	*T. malabaricus*	*T. gramineus*	*H. hypnale*
Male	148.34 (0.65)	164 (1.58)	144.33 (0.63)
Female	150.9 (0.85)	170.6 (0.57)	159.03 (0.74)

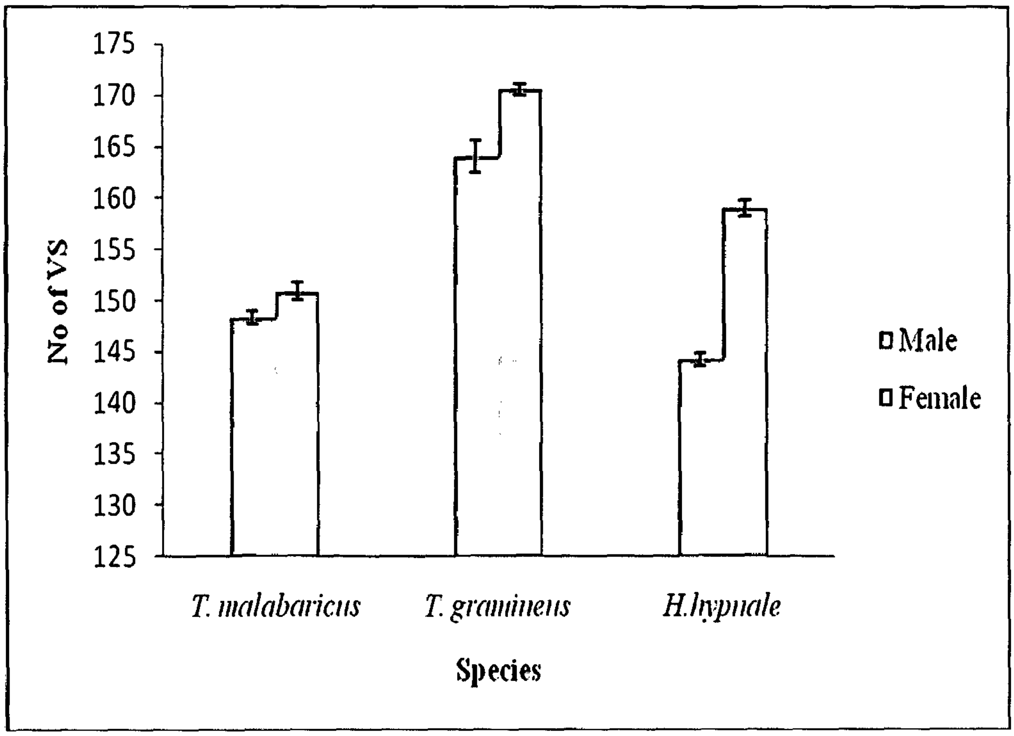


Figure 26: Graph showing average VS (SE) in pit viper species

Table 29: Average CS (SE) in pit viper species

Sex	*T. malabaricus*	*T. gramineus*	*H. hypnale*
Male	52.34 (0.54)	61.38 (0.87)	37.66 (0.48)
Female	50.52 (0.41)	60.37 (0.39)	45.11 (0.4)

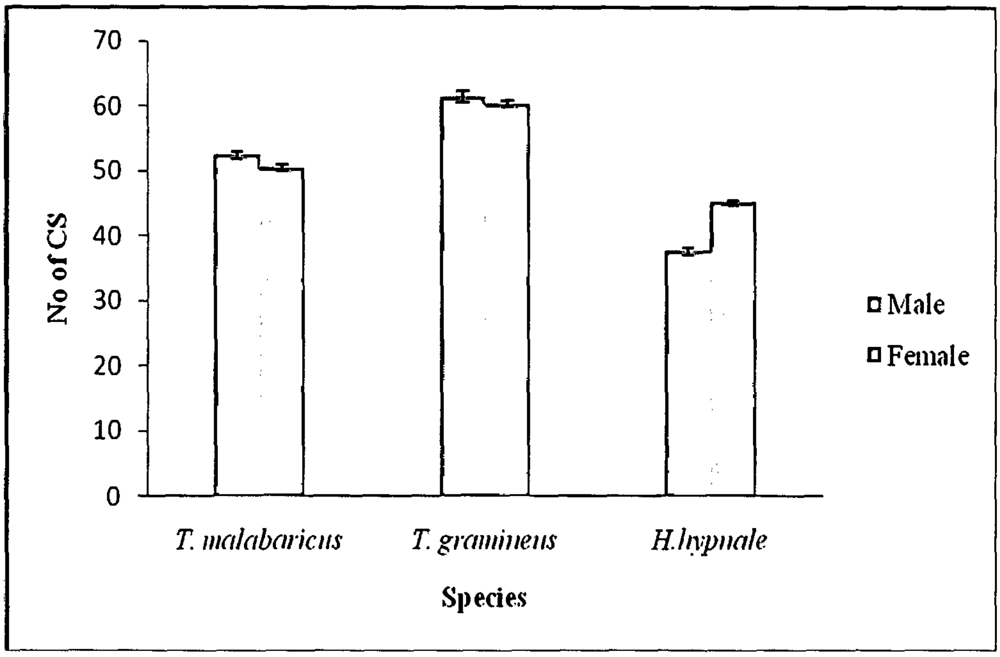


Figure 27: Graph showing average CS (SE) in pit viper species

Table 30: The SVL, CL, HDW, HDL and body mass (BM) for male and female neonates

H. hypnale

Morphometric measures	Males (n=7)	Females (n=11)
SVL (mm)	107.28 (1.01)	109.9 (0.65)
CL (mm)	16.85 (0.34)	21.63 (0.38)
HDL (mm)	8.71 (0.18)	10.63 (0.15)
HDW (mm)	4.71 (0.18)	6.81 (0.18)
BM (gm)	1.97 (0.03)	2.02 (0.01)

Foraging

All the three species of pit vipers studied were ambush predators and did not show any change in foraging and retreat sites. However, on few occasions during monsoon *T. malabaricus* and *T. gramineus* were encountered on the roads.

Trimeresurus malabaricus were found feeding on Forest calotes (*Calotes rouxi*), whereas, *T. gramineus* were seen feeding on some bird species. Other probable prey base recorded for *T. malabaricus* and *T. gramineus* were amphibians such as Malabar gliding tree frog (*Rachophorus malabaricus*), Common tree frog (*Polypedates maculates*), Travancore bush frog (*Philatus travancoricus*), White nosed bush frog (Philatus *leucorhinus*);Reptiles such as Dwarf gecko (*Cnemaspis sp*), Bark gecko (*Hemidactylus leschenaultii*), Flying draco (*Draco dussumieri*) and birds such as Thickbilled flowerpecker (*Dicaeum agile*), Tickell's flowerpecker (*Dicaeum erythrorhynchos)* and Whitebellied blue flycatcher (*Muscicapa pallipes)*.

Hypnale hypnale were found preying on Forest calotes (*Calotes rouxi*) and Little Skink (*Eutropis macularia*), other probable prey base of *H. hypnale* include amphibians such as Beddome's leaping frog (*Indirana beddomii*), Cricket frog (*Limnonectes limnocharis*), Verrucose frog (*L. keralensis*), Rufescent frog (*Frejerverya rufecence*), Burrowing species (*Tomoptera rolandae*), Indian burrowing frog (*Sphaerotheca breviceps*), Common Indian toad (*Bufo melanostictus*), Jerdon's narrow-mouthed frog (*Ramanella montana*) Indian bull frog (*Rana tigerina*) and Fungoid frog (*Rana malabarica*); reptiles such as Banded gecko (*Cyrtodactylus dekkanensis*), Brooke's gecko (*Hemidactylus brooki*), Common skink (*Mabuya carinata*) and Snake skink (*Riopa punctata*) etc.

During the feeding trials carried out in captivity it was observed that both the species preferred Common calotes and Forest calotes, whereas, ignored the Common house rat. *H. hypnale* preferred all the varieties of preys offered except the Common house rat.

Index of prey availability:

The abundance of prey available for *H. hypnale* is provided in table: 31. During the one year of the study a total of 332 reptiles belonging to 8 species and 222 amphibians belonging to 10 species were recorded. During summer (based on the availability of prey in the 13 primary quadrates) 112 secondary quadrates were sampled and a total of 86 reptiles and 31 amphibians were recorded. During monsoon a total of 148 secondary quadrates were sampled and a total of 169 reptiles and 140 amphibians were recorded. During winter a total of 153 secondary quadrates were sampled and a total of 105 reptiles and 51 amphibians were recorded. There was a positive correlation between the number of individuals of each species of pit viper and the number of prey found during different seasons [*T. malabaricus* ($r= 0.938$, $p< 0.001$), T. gramineus ($r= 0.0938$, $p< 0.001$) and *H. hypnale* ($r= 0.169$, $p< 0.001$)]

Table 31: The average abundance of prey (SE) available for *H. hypnale* in different seasons

Season	Secondary plot	Geckos	Skink	Agamid	Frog
Summer	112	6.25 (3.9)	9.5 (2.2)	5.75 (1.8)	7.75 (2.7)
Monsoon	148	11.5 (5.6)	20.75 (4.0)	10 (3.9)	35 (10.8)
Winter	153	7.5 (3.9)	12.75 (1.8)	6 (1.2)	12.75 (1.7)

PIT Tagging

Over a period of the present study one (out of 6) tagged individual of *H. hypnale* and two (out of 7) tagged individuals of *T. gramineus* were recaptured. The morphometric details of the recaptured pit vipers are provided in table: 32. The change in mass was low and therefore the increase in rate of mass was very less. No difference in SVL in all the three individuals and other morphometric parameters were observed.

Behavioral ecology

Thirteen active individuals of *T. malabaricus* were encountered of which 23.07 % (n=3) were moving whereas, 76.92 % (n=10) was encountered coiled with the neck forming S-coil and the head lying over body coil and generally forming an angle 'Y' 20° in relation to the ground. All the moving individuals were encountered at night whereas, out of coiled individuals 70 % were encountered during day and 30% were encountered at night of which 3 individuals were found to be in same position consecutively for 4-5 days during the full moon and waning period. Fourty individuals were encountered in foraging position of which 80 % were found during the day and 20 % were encountered at night, 23 individuals were found resting of which 86.95 % were encountered during the day and 13.05% were encountered at night, whereas, 14 individuals were encountered in basking position (Table: 33, Figure: 28).

Fourty three active individuals of *T. gramineus* were encountered of which13.95 % (n=6) were moving whereas, 86.04 % (n=37) were encountered coiled with the neck forming S-coil and the head lying over body coil and generally forming an angle 'Y' 20° in relation to the ground. Out of the moving individuals, all were encountered at night whereas, out of the coiled individuals 45.94 % were encountered during day and 54.05% were encountered at night of which 1 individual were found to be in same position consecutively for 4-5 days during the full moon and waning period. Fourty one individuals were encountered in foraging position of which 75.60 % were found during the day and 24.39 % were encountered at night. Eleven individuals of *T. gramineus* were found resting and all were found during the day, whereas, 5 individuals were encountered in the basking position (Table: 33, Figure: 28).

Sixty six active individuals of *H. hypnale* of which 4.5 % (n=3) were moving whereas, 95.45 % (n=63) were encountered coiled with the neck forming S-coil and the head lying over body coil and generally forming an angle 'Y' 20° in relation to the ground. Out of the moving individuals 33.33 % were encountered during the day and 66.66% were encountered at night whereas, amongst the coiled individuals 80.95 % were encountered during day and 19.04% were encountered at night. Twenty four individuals were encountered in foraging position of which 79.16 % were found during the day and 20.83% individuals were encountered at night. Out of the 40 individuals found resting 77.50% were found during the day and 22.50% were encountered at night, whereas, 36 individuals were encountered in the basking position (Table: 33, Figure: 28).

One-way ANOVA to test the difference in activity during day and night for each species separately was insignificant ($p>0.05$).

Amongst the 90 individuals of *T. malabaricus* encountered during the present study a single individual was found feeding on Forest calotes. The calotes was found engulfed from the anterior side as indicated by the visible tail and legs. However, one individual of *T. gramineus* was encountered feeding on bird (the species could not be identified as the bird was swallowed and only legs could be seen). Whereas, two individuals of *H. hypnale* were encountered feeding on the little skink and forest calotes and it was seen that it engulfed the prey from anterior end. While, in captivity it was observed that all the three pit vipers showed similar feeding behavior. *Hypnale hypnale* starts wagging the tail to attract the prey and then attacks the prey.

All the pit vipers were fed once after every eight days. Feeding trials were carried out after every two days but it was observed that the pit vipers ignored the prey. It was observed that all the three species held on the prey after the strike and during all the feeding trials it was found that the pit vipers capture the prey successfully with a single strike. After striking, all the three species start withdrawing the head so that the prey was hanged or till the prey became straight. Pit vipers of all the three species waited until the prey died or was immobilized. Then the snake gradually moved its jaw to the anterior end of the prey. During all the instance of feeding irrespective of the capture position (mostly anterior and mid anterior) the head of the prey was ingested first (Table: 34). It was observed that the prey size did not influence the ingestion site (anterior/ posterior). The time taken by the pit vipers for ingesting the prey depended on the prey size (Table: 35). The feeding process of arboreal and terrestrial pit vipers is shown in plate: 10 (a-b) and plate 11(a-b) respectively.

There was a positive correlation between the prey size and time taken for the ingestion of prey when compared for all the three species [*T. malabaricus* ($r= 0.963$, $df= 6$, $p< 0.01$), *T. gramineus* ($r= 0.961$, $df=6$, $p<0.01$) and *H. hypnale* ($r=0.766$, $df=6$, $p<0.02$)]. The analysis of variance (two-way ANOVA) to test the difference between the prey size and time taken for the ingestion of prey by all the three species was significant ($F=5.75$, $df=2$, $p= 0.006$).

Anti predatory behavior:

These pit vipers (all 3 species) remain highly camouflaged in their respective substrate; the arboreal species (*T. malabaricus* and *T. gramineus*) mask the thick green foliage of a branch or on the twig and the terrestrial species (*H. hypnale*) mask the leaf litter. Further, all the three species remain mostly motionless move briskly if disturbed. As and when they are disturbed either by a predator or otherwise, they coil their body in "S" shape and attack the predators as a defensive mechanism. On few occasions it was observed that they become very aggressive when disturbed and give severe bites to victim and inject venom.

Table 32: The morphometric details of the recaptured pit vipers

Snake ID	Species	Sex	No. of days after which snakes was recaptured	Distance (in air) between site of release and recapture(m)	SVL at capture (mm)	SVL at Recapture (mm)	Increase rate in SVL mm/day	Change in mass (gm)	Increase rate in mass gm/Day
0006833948	*T. gramineus*	F	23	52	448	448	0	1.3	0.05
000683126C	*T. gramineus*	F	8	25	555	555	0	0.2	0.025
00068301E4	*H. hypnale*	F	10	20	422	422	0	0	0

Table 33: Number of individuals of pit vipers exhibiting different behaviours

Species	Active	Foraging	Resting	Basking
T. Malabaricus	13	40	23	14
T. gramineus	43	41	11	5
H. hypnale	66	24	40	36

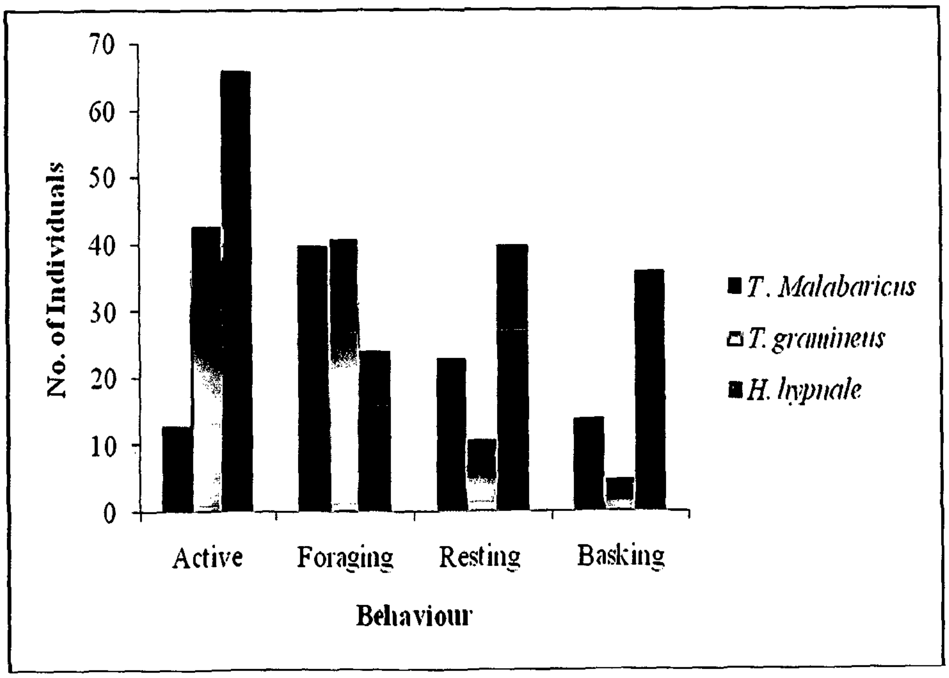


Figure 28: Graph showing number of individuals of pit vipers exhibiting different behaviours

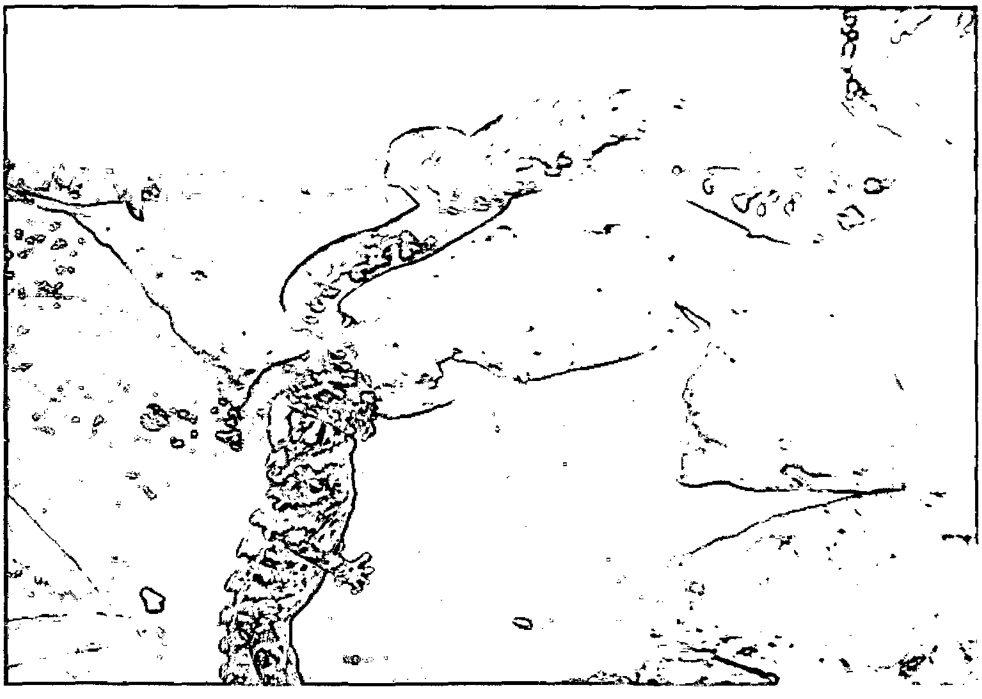
Table 34: Frequency of capture position and prey ingestion direction

Species	Prey type	Capture position		n	Frequency of Head first ingested (%)
		Anterior	Mid Anterior		
T. malabaricus	Forest Calotes	3	2	5	100
	Common Calotes	2	1	3	100
T. gramineus	Forest Calotes	3	1	4	100
	Common Calotes	2	2	4	100
H. hypnale	Skinks	3	0	3	100
	Frogs	1	1	2	100
	House Lizard	1	2	3	100

Table 35: The time taken by the pit vipers for ingesting the prey of different sizes

Species	Prey type	Average Prey size (mm)	Average Time taken to ingest the prey (minutes)
T. Malabaricus	Forest Calotes	144.6 ± 11.6	37.2 ± 1.7
	Common Calotes	170 ± 26.4	40.33 ± 5.05
T. gramineus	Forest Calotes	165.5 ± 9	39 ± 1.68
	Common Calotes	160.7 ± 15.7	38 ± 4.04
H. hypnale	Skinks	70 ± 5.778	10.6 ± 0.6
	Frogs	61 ± 11.03	13 ± 3
	House Lizard	105 ± 11.64	15.33 ± 0.33

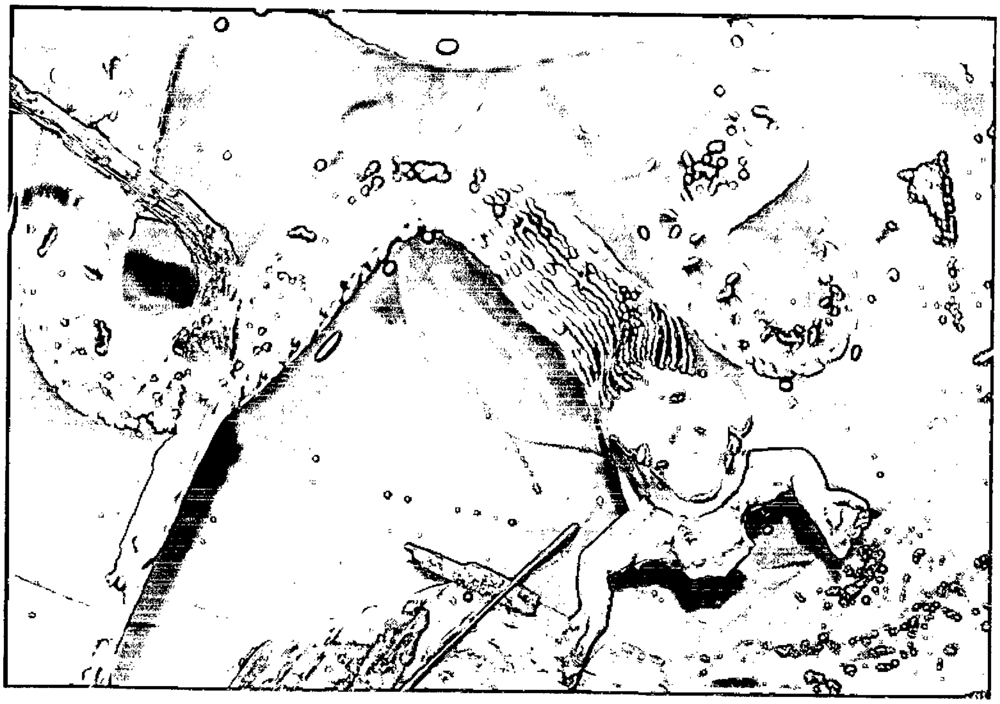
(a)



(b)

Plate 10: Feeding process of arboreal pit viper *T. malabaricus* (a) the pit viper striking its prey. (b) Pit viper engulfing the prey

(a)



(b)

Plate 11: Feeding process of terrestrial pit viper *H. hypnale* (a) the pit viper striking its prey. (b) Pit viper engulfing the prey

Threats

Pit vipers were found to be exposed to numerous threats in their habitat. Considerable threats such as regular movements and utilization of natural resources in haphazard way were seen on pit vipers in MWS as a result of human inhabitation. Cattle's grazing was seen as a common phenomenon in this area. Construction of roads was also seen during the study period. Transects falling under Surla, Sathre, Kumthal, Ivrem, Krishnapur are visited by tourists, especially during the monsoon which coincides with the peak season of pit vipers. Most of the study transects consist of cashew plantations. Weed clearance is carried out regularly every year during post monsoon and summer in cashew plantations for harvesting the cashew crop. During this process *H. hypnale* are killed out of fear by labourers. These incidents were observed throughout the study sites from north Goa to south Goa (Plate: 12 a-b).

Severe threats on pit vipers were seen in BWS due to human disturbances. A continuous flow of tourists was seen throughout the year which results in extensive disturbance to the habitat. This Sanctuary has an added tourist attraction in the form of a zoo, a garden area which is visited by these tourists.

Pit vipers in the BMWS and NP face tremendous pressure due to presence of road including the national highway which segregates the national park into two isolated patches. Continuous vehicular movement in this area makes it difficult for pit vipers to cross the road and in bargain they get killed under the running vehicle. Some transects including Vazra waterfall, Dudhsagar are frequently visited by tourists / nature lovers.

Considerable mining activity exists in the close proximity of this sanctuary resulting in additional threat to the pit vipers. A single specimen of *T. gramineus* was found killed under running vehicle while crossing the road at Kule. It was seen that plenty of *H. hypnale* were killed by labourers during weed clearance in the cashew plantations.

Netravali Wildlife Sanctuary also faces similar threats like MWS; this sanctuary also has human settlement within the sanctuary and utilizes the entire natural resources on regular basis. Their only livelihood is agriculture and cashew. Therefore, every year it was seen that They undertake deforestation and new areas are encroached to carry out agricultural activities which in turn put tremendous pressure on the existing natural forest. Killing of *H. hypnale* was seen in cashew plantations in NWS.

Like MWS and NWS, CWS also consist of human settlement within the sanctuary and access road network is prevailing in the sanctuary. Many tourists visits the transects such as Hattipaul, Depo area, Tree top area, Kuske, Bela road. Regular vehicular movement by the inhabitants and tourists in the sanctuary disturbs the habitat.

Predators such as Crested Serpent-eagle, Coucal, Peacock and Cobra were sighted preying on *H. hypnale*. The increasing population of peacock has put tremendous pressure on the population of *H. hypnale* and in some areas the population is dwindling at a faster rate. Other possible predators of all the three species of pit vipers include shikra, mongoose, monitor lizard and nocturnal predators such as civet cats and owls. The same was also reported by locals.

Impact of tourism:

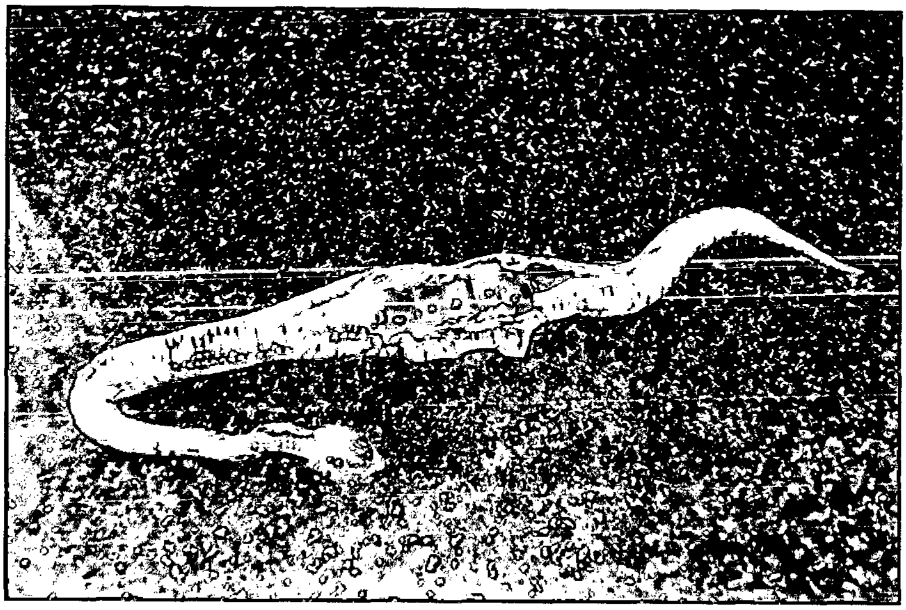
The number of tourists that visited BWS during the study period is given in table: 36, figure: 29. It was observed that maximum numbers of tourist (63,992) visited BWS in the year 2008-2009 and minimum (34,339) was in the year 2006-2007. In the year 2005-2006 43, 468 tourist visited BWS. In the year 2006-2007 there was 21% reduction in the number of tourist visiting BWS from the starting year (2005- 2006), Since then the number of tourist visiting BWS has increased, in the year 2007-2008 56.6% increase from the year 2006- 2007. In the year 2008- 2009 there was 19% increase from the previous year and 47.22% increase from the starting year.

The number of tourists that visited BMWS during the study period is given in table: 36, figure: 30. It was observed that maximum numbers of tourist (80,644) visited BMWS in the year 2008-2009 and minimum (70,351) was in the year 2006-2007. In the year 2006-2007 there was 4.85% reduction in the number of tourists visiting BMWS. In the year 2007-2008 there was 13.57% reduction in the number of tourist visiting BMWS from the starting year (2005- 2006), Since then the number of tourist visiting BMWS has increased. In the year 2008- 2009 there was 26.21% increase from the previous year and 9.08% increase from the starting year.

The number of tourists that visited CWS during the study period is given in table: 36, figure: 31. It was observed that maximum numbers of tourist (6,075) visited CWS in the year 2007-2008 followed by 5,177 tourists that visited CWS in the year 2008-2009 and minimum (2,781) was in the year 2005-2006. In the year 2006-2007 there was

118.45% increase in the number of tourist visiting CWS from the starting year (2005-2006), whereas, in the year 2007-2008 there was 23.49% reduction in the number of tourists from the previous year. In the year 2008- 2009 there was 11.38% increase from the previous year and 86.16% increase from the starting year.

The analysis of Variance (one-way ANOVA to test whether the number of tourist influences the abundance of snake with respect to each site (BWS, CWS and BMWS) showed that at BWS ($p=0.0002$, $df=1$, $F=58.1$), at CWS ($p=0.0005$, $df=1$, $F=44.75$) whereas it was insignificant ($p>0.05$) at BMWS.



(a)

(b)

Plate 12 (a-b): Gravid females killed by locals during weed clearance in cashew plantations

Table 36: The number of tourists that visited CWS, BWS and BMWS during the study period

YEAR	BMWS	BWS	CWS
2005 – 2006	73,934	43,468	2781
2006 – 2007	70,351	34,339	6075
2007 – 2008	63,898	53,776	4648
2008 – 2009	80644	63,992	5177

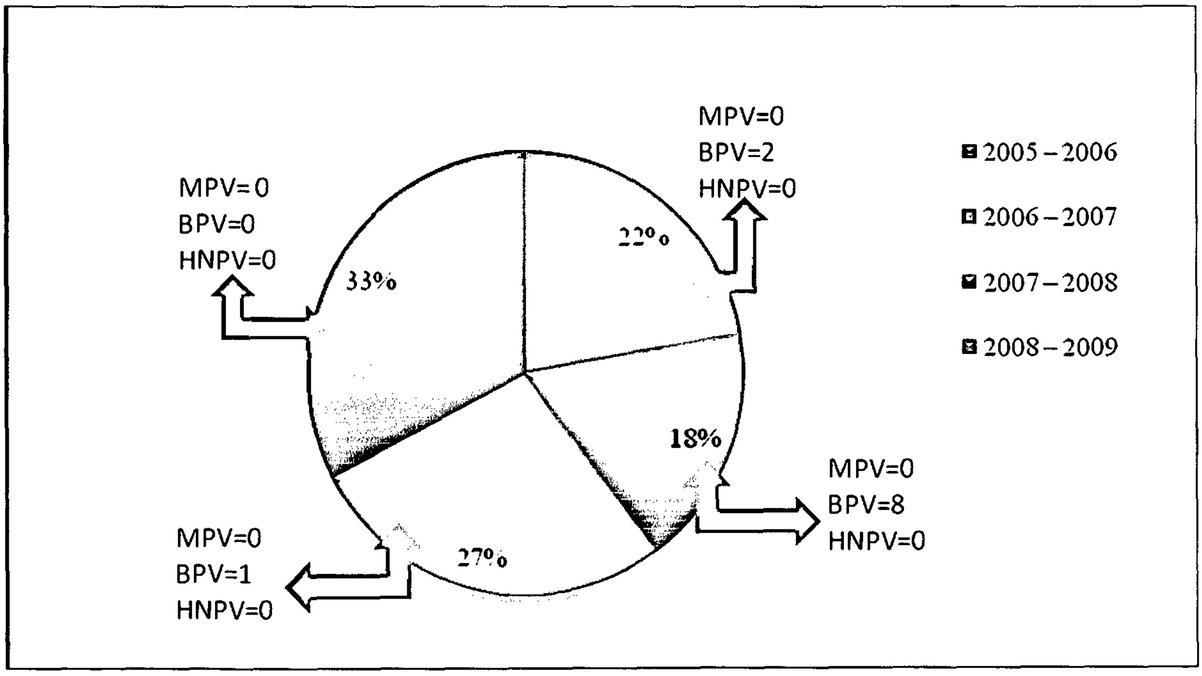


Figure 29: Pie chart showing the number of tourists that visited BWS during the study period

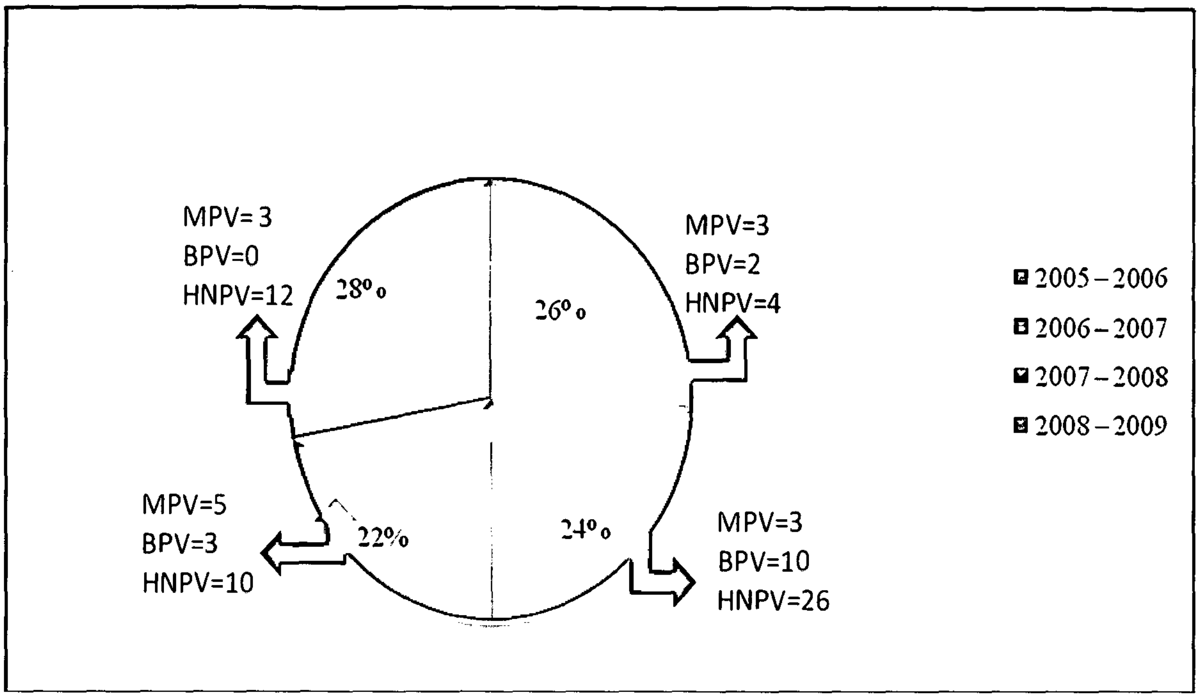


Figure 30: Pie chart showing the number of tourists that visited BMWS during the study period

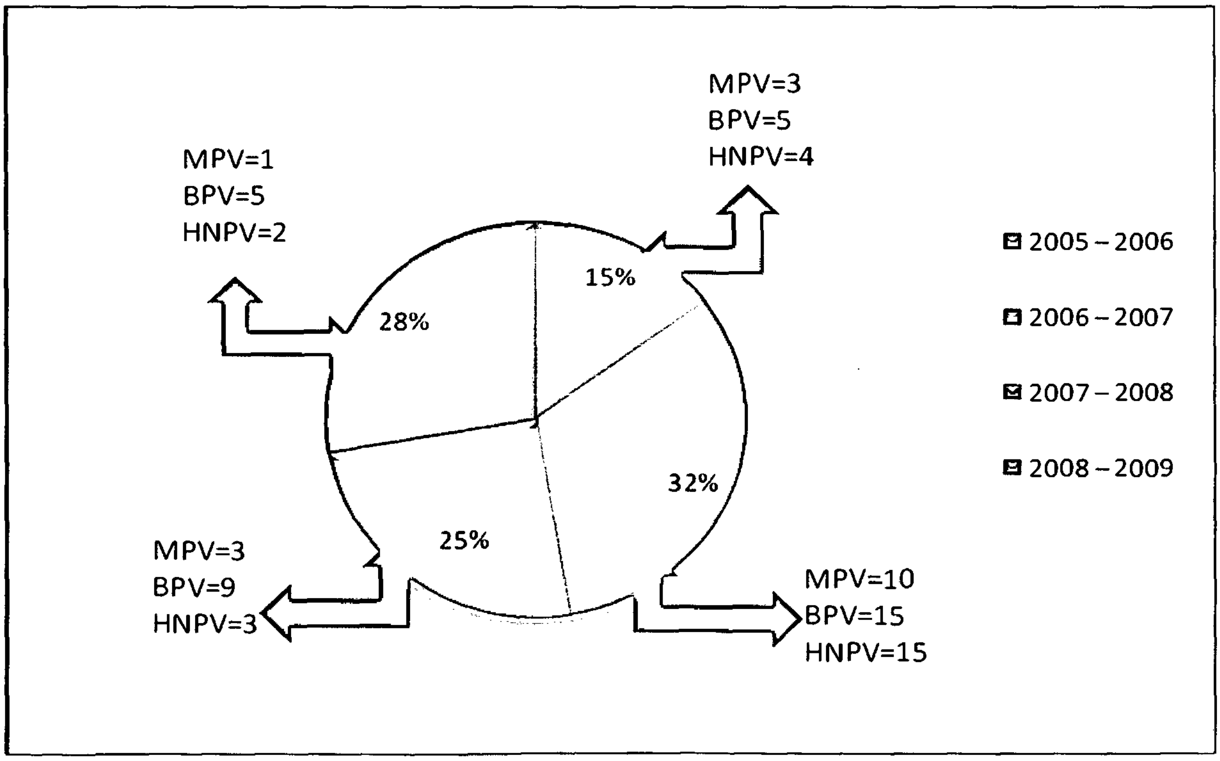


Figure 31: Pie chart showing the number of tourists that visited CWS during the study period

Phylogenetic study

High molecular weight DNA was isolated from the tissue samples (Figure: 32). The DNA obtained was subjected to PCR amplification with the two molecular markers namely, cyt b and 16S rRNA. The amplified products were run on a 2.5 % agarose gel (Figure: 33). The amplicons were sequenced on both the strands to increase the accuracy and subjected to phylogenetic analysis. The phylogenetics status of the three pit vipers species from Goa namely, *T. malabaricus, T. gramineus* and *H. hypnale,* was studied using partial sequences of two mitochondrial DNA markers; cytochrome b (cyt b) and 16S rRNA.

The neighbor joining (NJ) phylogenetics tree based on the cyt b sequences of the three Goan pit viper species and the cyt b sequences of other pit vipers from the NCBI database clearly formed three major clades consisting of the three groups of pit vipers i.e. Indian sub-continent, Indo-Malayan and New world vipers (Figure: 34). All relationships were assigned with greater than 95% confidence and with a high bootstrap support. The two *Trimeresurus* species from Goa occupied their position in the Indian sub-continent group. With both the markers, *T. trigonocephalus* appeared to be the nearest neighbor of *T. gramineus and T. malabaricus.* However, the third pit viper *H. hypnale* occupied a basal position in the phylogenetics tree falling out of the three major groups of the pit vipers. The 16S rRNA sequences also depicted the similar kind of groups amongst the pit viper species under study (Figure: 35) with an exception of *H. hypnale* falling in the group of New world pit vipers.

Further, the maximum parsimony (MP) tree also showed the three major groups and the similar topology with the two mitochondrial markers. The preliminary results based on cyt b gene and control region of mitochondria have shown significant number of haplotypes and genetic variation amongst the individuals of *H. hypnale* collected from different geographic locations of Goa/Western Ghats. According to the preliminary observation of *H. hypnale* population (n=36), four haplotypes were observed based on three variable sites in the partial sequence of cyt b gene. The nucleotide (Pi) as well as the haplotypes (Hd) diversity was found to be very low i.e. 0.00049 and 0.3032 respectively. No significant differentiation was observed in the population (Tajima D index= -1.24, $p > 0.10$). H1 haplotype was predominant and shared by most of the individual animals (n=30) from BMWS and MWS. Haplotypes H3 and H4 were unique to the MWS.

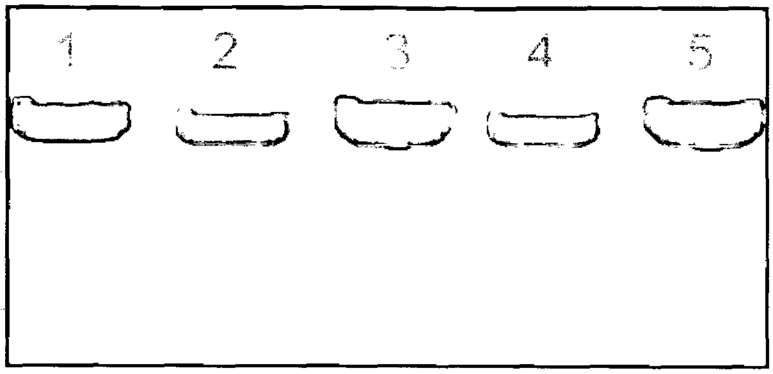


Figure 32: Genomic DNA (in 0.8 % agarose)

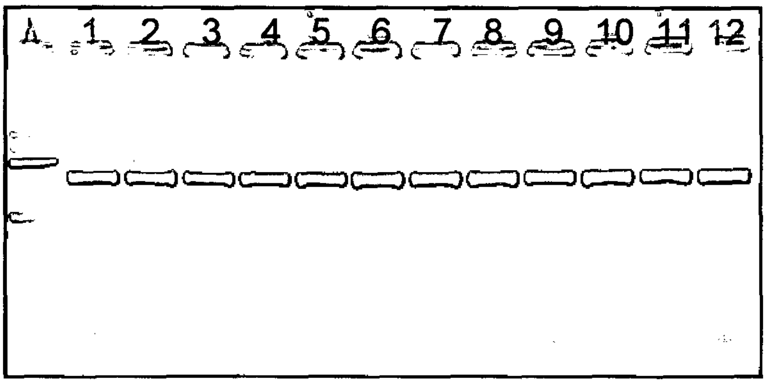
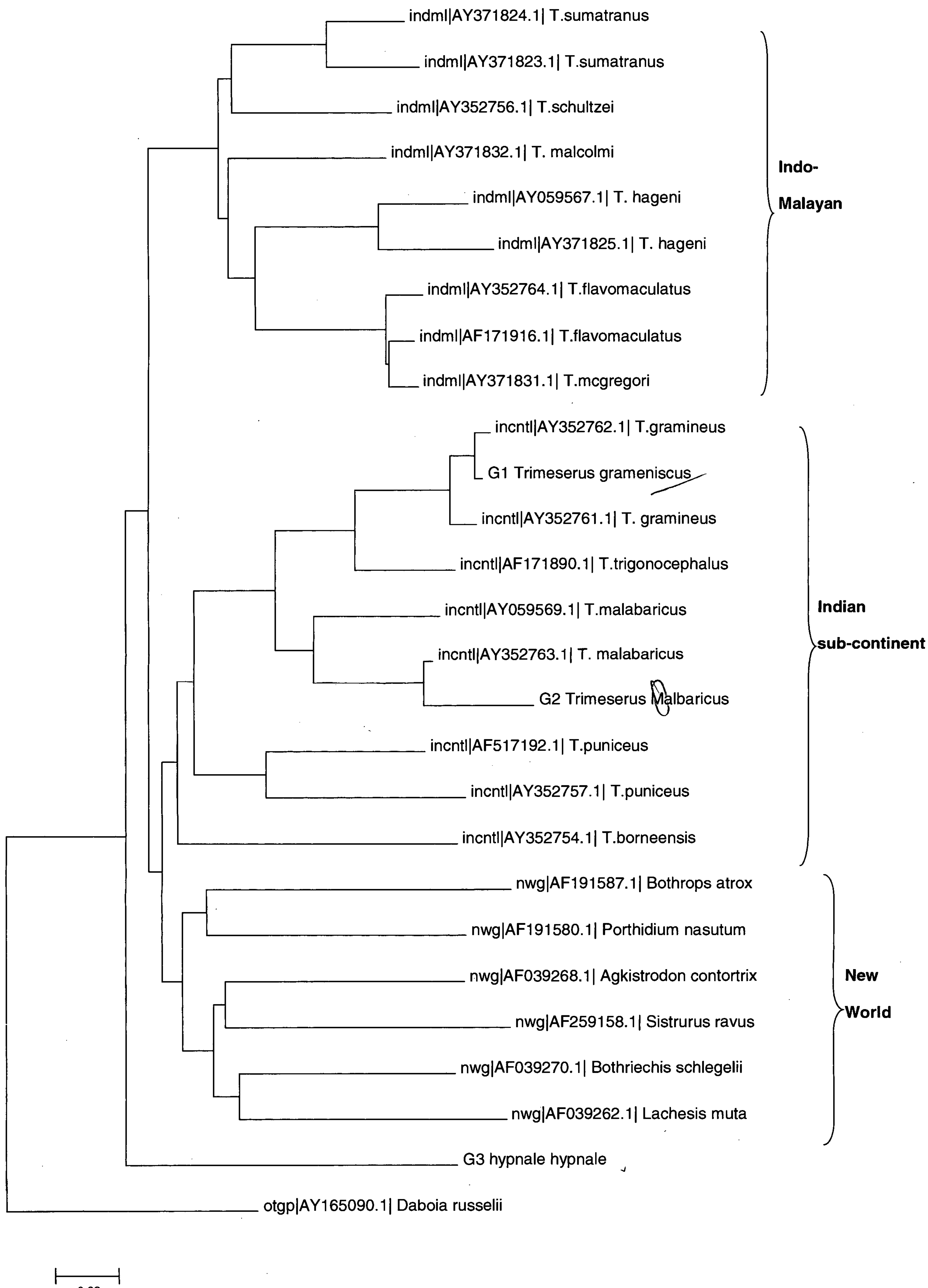
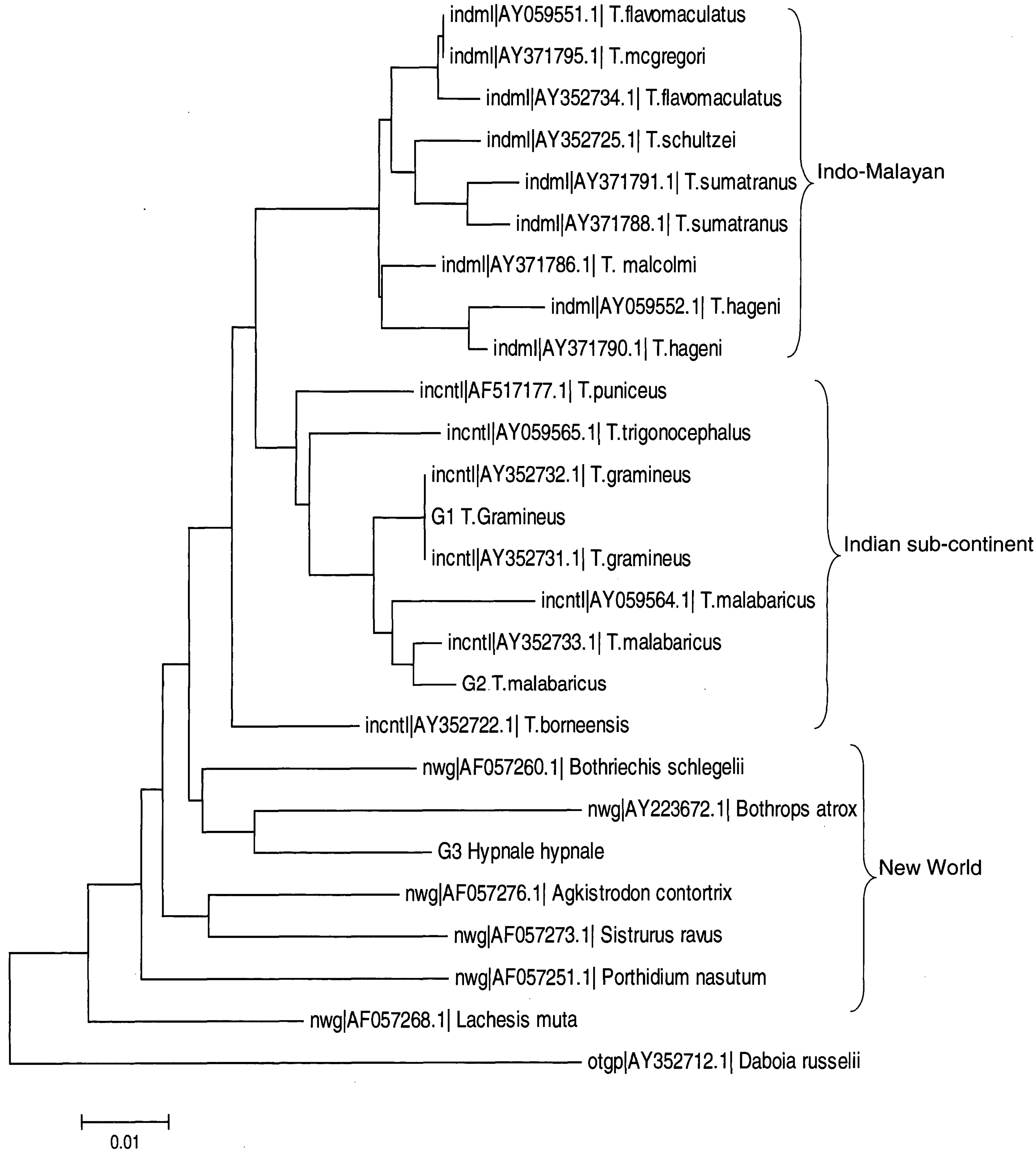


Figure 33: Amplified DNA (in 2.5 % agarose)



igure 34: A neighbor joining phylogenetic tree between the different species of pit vipers based on sequences of cytochrome b. *Daboia russelli* as used as the out-group. The value given at the bottom is the rate of substitution of nucleotide bases



;ure 35: A neighbor joining phylogenetic tree between the different species of pit vipers based on sequences of 16S rRNA. *Daboia russelli* s used as the out-group. The value given at the bottom is the rate of substitution of nucleotide bases.

CHAPTER 4

DISCUSSION AND CONCLUSION

The study has revealed the presence of three species of pit vipers in the Western Ghats of Goa region namely *T. malabaricus* (Malabar pit viper), *T. gramineus* (Bamboo pit viper) and *H. hypnale* (Hump-nosed pit viper). Reptile species are not randomly distributed in space, but inhabit distinct microhabitat (Heatwole, 1982) and understanding the spatial distribution of organisms has been essential in ecology (Thorpe, 1945; Turner, 1989). The distribution of all the three species is restricted to Western Ghats and its foothills. The distribution and abundance of all three species of pit vipers varied as their habitat-use was different. It was observed that out of the total 45 transects surveyed *H. hypnale* was found in 31 transects, whereas, *T. malabaricus* and *T. gramineus* were found in 11 and 18 transects respectively. An organism's distribution can be analyzed by knowing its habitat preference, and the habitat of a particular species may be described as the array of environments in which an animal lives, which can be estimated by several habitat characteristics (Whittaker *et al.*, 1973).

The three species showed considerable fluctuations over the course of the present study in terms of total numbers. *Hypnale hypnale* showed highest abundance during all the years and in all the study sites followed by *T. gramineus* and *T. malabaricus*. This could be due to the availability of habitat, which is much more for *H. hypnale* as it was observed that *H. hypnale* is more widely distributed (Figure: 3). ANOVA depicted that the abundance of the three species varied insignificantly over the years. Changes in abundance of pit vipers might be due to change in encounter rate, their activity level or dispersal, of which both of the latter processes are important as pit vipers are ambush predators, remain motionless for a longer period of time and are highly camouflaged with the substratum they use. Sun *et al.* (2001) suggested that the weather conditions during survey influences the number of snakes encountered during the survey. Almost the entire Western Ghat region in Goa is protected. Nature reserves protect important natural habitats but also offer public opportunities for outdoor leisure activities that may have negative effect on wildlife (Hammitt and Cole, 1987). Data obtained from the Forest Department on the number of tourists visiting the sanctuaries and national parks (BWS, CWS and BMWS and NP) every year suggests that the number of tourist visiting the sanctuaries and national parks has increased over the years. The analysis of variance to test whether the number of tourist influences the abundance of snake with respect to each site showed that at BWS and CWS there was a significant influence of number of tourists on the number of pit vipers encountered over the years. Thus, increased human activity may affect the snakes in terms of abundance; more detailed research is required before this conclusion can be accepted. Also other negative effects of human disturbance not addressed in this study needs to be investigated.

It was seen that all the three species were distributed in all study locations, barring BWS, where *T. malabaricus* and *H. hypnale* were not recorded during the present study. BWS is the smallest wildlife sanctuary of Goa and amongst the forest type preferred by *H. hypnale* only cane brakes, wet bamboo brakes, southern secondary moist mixed forest and west coast semi-evergreen, moist bamboo brakes and lateritic semi evergreen forest patches prevail in BWS, whereas, amongst the forest type preferred by *T. malabaricus only* southern moist deciduous forests, southern secondary moist mixed forest, west coast semi-evergreen forest, moist bamboo brakes and lateritic semi-evergreen forest patches prevail in BWS (Table: 10). Another possible factor which has affected this species may ie the presence of a zoological garden in the sanctuary which attracts many tourists and a ;ontinuous flow of vehicles which causes disturbances of the habitat; few authors Peterson, 1990; Brown, 1993; Parent and Weatherhead, 2000) believe human listurbances can affect the snakes in terms of their distribution. Secondly *H. hypnale* hows a shift in habitat during different seasons, for which the hygrothermal profile such ıs cool and moist climate, leaf litter, suitable retreat and breeding site is not available at 3WS throughout the year. Ishwar *et al.* (2001) and Rocha *et al.* (2008) suggested that estricted distribution and differences in snake abundances between areas could occur due o geographic factors such as altitudinal gradient, drainages (manmade, especially for soil ınd water conservation), streams and rivulets which could form barriers to the dispersal ›f animals. ANOVA showed that the abundance of each species with respect to the study ;ites and the abundance at each site with respect to the three species varied nsignificantly. The variation in abundance and distribution of the pit vipers between sites ınd of all the three species at given study site may be due to the habitat specificity and he proportion of the preferred habitat present in the different study sites.

Allen and Starr (1982), O'Neill *et al.* (1986) and Kotliar and Wiens, (1990) ;uggested that apparent landscape- level preferences could merely be an artifact of ;uitable microhabitats being restricted to preferred habitat. Some authors have 'ecognized climatic factors and coarse-grained changes in habitat as limiting the listributions of most specie of reptiles, both at local (Brown and Alcala, 1961; Inger *et ıl.*, 1987; Scott, 1976) and regional scales (Heyer, 1967). Also, the ability to see and locate the species may provide differential probability of encounter of individuals of different species in different microhabitat and /or different times of the day.

Hypnale hypnale and *T. gramineus* preferred a broader range of altitude as compared to *T. malabaricus*, however *T. malabaricus* was also found at lower altitude in CWS suggesting that it is the ideal habitat with suitable hygrothermal profile and prey base which is the basic factor influencing distribution of these species. Some researchers (Porter, 1972; Campbell and Solorzano, 1992; Huang *et al.*, 2007) consider ambient temperatures to be an important environmental factor limiting the altitudinal distribution of reptiles. It was also observed that the total pit viper density was highest at low altitude and lowest at high altitude except for *T. malabaricus* which showed high densities at low and high altitude and lowest densities at mid altitude. ANOVA showed a significant pattern of distribution of all the three species along the altitudinal gradients. The distribution of these species with respect to elevation suggests that species distributions are hardly affected by the environmental (physical environment) discontinuities. Hofer *et al.* (2000) suggested that the species sensitivity to ecotones associated with changes in forest type should decrease the relative effect of the gradient on the distributional pattern at the level of the entire species group.

It was also seen that the abundance of all the three species varied in different seasons and the seasonal difference in abundance of each species was highly significant statistically. The abundance was highest in monsoon compared to summer and winter. The highest abundance during monsoon was due to the suitable climatic conditions such as low temperature (22-24 ^{0}C), high humidity and rich prey base. The wet season brings about an enormous change in resource availability. The water availability and luxurious vegetation growth after monsoonal rains may provide food and shelter for many animal species, as well as change the array of hydric and thermal microhabitats that are available (Hofer *et al.*, 2000). In summer and winter the prey base (such as frogs) and suitable climatic conditions are restricted to patches in the vicinity of water bodies in the protected areas. The analyses of index of prey availability during the 2007-2008 at CWS showed a positive correlation between the number of individuals of each species encountered during different species and the prey availability, suggesting that the abundance of pit vipers during different seasons is influenced by the prey availability. The findings are in accordance with Sun *et al.* (2000) who suggested that prey availability and abiotic factors, mainly temperatures are the indications that drive seasonality in snakes. Noticeable changes in encounter rates during different seasons are associated with significant biological events such as hibernation, mate-searching by adult males, egg-laying migrations by gravid females, and hatching of eggs (Bonnet *et al.*, 1999).

Habitat Ecology

Trimeresurus malabaricus and *T. gramineus* are arboreal, whereas, *H. hypnale* is terrestrial in nature, however, a semi- arboreal behavior was also observed in *H. hypnale*. The present results augment the report of Murthy (1990). Terrestrial and arboreal habitats differ greatly in the types and amount of food availability, susceptibility to predators, and physical factors such as temperature and humidity. As a consequence of these differences many species have become highly specialized for either terrestrial or arboreal life and rarely undertake alternative habitat (Plummer, 1981; Luiselli *et al.*, 2000; Vilt *et al.*, 2000). Identifying habitats that are used selectively is the first step in determining a species critical habitat. Habitat selection occurs at different spatial scales. At the landscape level, animals select most suitable habitats (i.e. forest, field, wetlands) and then within habitats, animals select microhabitats that fulfill their requirements (Cody, 1985; Orians and Wittenberger, 1991). The habitat composition within each species of pit vipers home range differed from habitat composition within the total study areas. *Trimeresurus malabaricus* predominantly occupied tropical evergreen forest and rarely used moist deciduous forest. *T. gramineus* and *H. hypnale* were observed largely in wet bamboo brakes, tropical semi evergreen and moist deciduous forest.

At the macrohabitat scale, the locations of all the three pit viper species differed. Their home range was restricted to forest and forest edge habitat, thus, avoiding open habitats. These findings provide confirmation to the findings of Klauber, (1972) that, most species of *Trimeresurus* are found in forests, as *T. malabaricus* had higher encounter rate in forest than forest edges thus, showing preference for thick vegetation, selecting a home range in forest habitat. Whereas, it contradicts his findings that in contrast to *Trimeresurus* most species of Crotalus, inhabit open habitats as, *T. gramineus* and *H. hypnale* had almost equal encounter rate in forest and forest edges and none was encountered in open habitat. ANOVA showed a significant difference in habitat (forest and forest edge) utilization by *T. malabaricus* whereas, the habitat use by *T. gramineus* and *H. hypnale* did not differ significantly. Unfavorable range of habitat types can occur even within a small area, and animals use this diversity in multifaceted ways. The organism's 'choice' of particular habitat features apparently relates to advantages and disadvantages linked with each option (Krebs and McCleery, 1984). The forest edge is located at the boundary of the coolest habitat (forests) that is always shaded and the warmest habitats (open habitats) that receive full solar radiation, thus, snakes in forest edges always have access both to a protection from forest and to the warmest possible habitats (open habitats). Weatherhead and Charland (1985) proposed that snakes might prefer edges because increased solar radiation allows snakes to bask to increase body temperatures. Presumably, edges also facilitate thermoregulation because they provide simultaneous access to open sunny habitats to increase body temperatures and shaded forests to decrease body temperatures. Carfagno and Weatherhead (2006) reported intraspecific and interspecific variation in use of forest and forest edge habitat by snake to occur as a result of thermoregulatory needs.

Thus, a higher diversity in macrohabitat use in pit vipers may be associated with inhabiting structurally more intricate habitats, such as tropical forests. However, when the preference for the habitat was tested for males and females of each species separately it showed insignificant pattern of habitat use, suggesting that habitat utilization does not differ between sexes.

The study also revealed that the arboreal species (*T. malabaricus* and *T. gramineus*) did not show any change in habitat preference during different seasons.

However, *H. hypnale* showed a shift in habitat from natural confines within the protected areas into the cashew plantations. There are no previous records of such a shift in habitat shown by the *H. hypnale*. Interestingly, such a shift in habitat coincides with the breeding season and these interim movements are mostly exhibited by the females, especially by the gravid females. Males were very rarely encountered in the cashew plantations. ANOVA showed no significant difference when tested for the preference of forest and cashew separately for different seasons, this could be due to the fact that the entire sample i.e. males and females in both forest and cashew was used for the analysis, whereas, when the habitat preference (forest and cashew) was tested for gravid and non-gravid females of *H. hypnale* it showed a significant difference in habitat preference.

The transient shift by the gravid females into the cashew monoculture merits discussion. The microhabitat requirement of the breeding individuals is perhaps best met in the cashew plantation owing to the thickness of the leaf litter. Carrying a developing clutch can also weaken the ability of gravid females to escape from predators (Shine, 1980; Seigel *et al.*, 1987; Brown and Shine, 2004a; Brown and Shine, 2004b; Winne and Hopkins, 2006). Gravid female reptiles often maintain higher body temperatures through behavioral modification, such as increased basking (Shine, 1980; Schwarzkopf and Shine, 1991; Blazquez, 1995; Brown and Weatherhead, 2000; Blouin-Demers and Weatherhead, 2001b), which could increase vulnerability to predators. Cashew plantations might provide a good amount of leaf litter and also opportunity to bask. Thus the leaf litter thickness may provide a good hide out to these gravid females. The leaf litter thickness in forest and cashew during post monsoon and winter differed significantly, wherein the leaf litter thickness in cashew was more than in the forest. According to Block and Morrison (1998) leaf litter depth is an important factor in habitat selection in amphibians and reptiles. Reinert (1993) suggested that the need to locate essential resources such as food, shelter and gestation sites, manipulate habitat selection by snakes.

A few studies (Houston and Shine, 1994; Mullin and Cooper, 2000; Shine and Sun, 2002) showed that reptiles prefer habitat with high prey abundance. Janzen and Schoener (1968) suggested that factors such as general reduction in the forest productivity in the dry seasons affect most animals including reptiles and their prey. Thus, less prey availability is the possible reason for the shift in habitat from the forest area to the cashew plantation. This also explains why there is a difference in sightings during different seasons. Henderson *et al.* (1979) reported that rainfall might affect snake activity indirectly by affecting prey availability. Since snakes are predatory in nature, therefore their local distribution might be influenced by distribution of prey abundance (Dar *et al.*, 2008). The present study revealed that leaf litter core temperature was $1.96 \pm 1.32\ ^{0}C$ lower than the ambient temperature, whereas the humidity was 5 ± 1.87 % higher than ambient humidity in the cashew plantation as compared to the forest area. This cool and humid climate below the leaf litter provides a good micro-climate for arthropods which is the major prey base for the reptiles. This in turn forms the prey base for the *H. hypnale*. This is supported by Kumar *et al.* (2001). Lima and Dill (1990) suggest that specific features of the leaf litter help reptiles to meet the conflicting demands of thermo-regulation, predator avoidance and participation in other activities.

Microhabitat:

There was no vast difference observed between the temperature and humidity between the study areas. However, the microhabitat use varied seasonally in all the three species, during monsoon they were found in all the transects, whereas, in summer and winter they were observed in 35 transects which include transects having water bodies in the vicinity, thick vegetation and transects in the cashew plantations (for *H. hypnale*). The individuals of all the three species were encountered in the regions having cool climate (segments of the transects with lower temperature and higher humidity) suggesting that the species prefer cool and moist places. Daltry *et al.* (1998 b) reported that the pit vipers typically remain motionless in areas with dense cover of undergrowth, suggesting this species is hygrophilic in nature.

Trimeresurus malabaricus and *T. gramineus* remain camouflaged in the thick canopy of the trees. 85.55% of *T. malabaricus* were encountered on the vegetation of which 68.83% were sighted in the areas having thick tree canopy cover and 94% of *T. gramineus* were encountered on vegetation of which, only 34.04% were sighted in the areas having thick tree canopy cover. Also the arboreal pit vipers exhibited no preference for vegetation structure at low ambient temperature (monsoon), except for avoiding vegetation with bare branches and no leaves. However, during summer they were distributed in regions with thick tree canopy and thick vegetation. It was observed that the tree species utilization did not differ significantly between the two arboreal species and also between the two sexes of both the species. Meik *et al.* (2002) suggested that the type of vegetation can have a significant impact upon habitat availability for ectotherms by affecting the thermal characteristics of probable habitats. The types of vegetation selected by pit vipers as retreat sites are also influenced by temperature cues; moreover, the physical environment within a habitat structure may influence the thermal attributes and microclimate of a reptile's selected habitat (Christian *et al.*, 1983; Huey *et al.*, 1989; Pringle *et al.*, 2003; Heard *et al.*, 2004; Tsairi and Bouskila, 2004; Webb *et al.*, 2004). This explains the difference in encounter rate of the two arboreal species in thick and sparse vegetation. Janzen (1976) suggested that vegetation cover plays a crucial role in concealing snakes from predators. Thus, arboreal snakes might be selecting the thick vegetation as a defense approach; however there is no much data pertaining to predator density affecting the habitat selection by the arboreal pit vipers and cannot assess this possibility formally.

Individuals of the arboreal species were also encountered while crossing the roads during night hours; this could be due to the thigmothermic reaction to warm surfaces, such as asphalt roads at night in nocturnal crotalines (Klauber, 1972). Since, the arboreal species were found crossing the roads during the monsoon, this excursion to the ground could be driven by the availability of prey, especially frogs which is an easy and abundant prey available during monsoon on the road and the findings also suggests that since, majority (i.e. all the individuals of *T. malabaricus* and 83.33% *T. gramineus*) of the individuals sighted on the roads were males, the search for mate could also result in such excursions. Shine *et al.* (2004) suggested that pheromonal trail following may result in males traveling further and longer to locate females. *Trimeresurus malabaricus* was also found in the rock crevices near water bodies this may be mainly due to their hygrophilic nature (discussed earlier).

Amongst the arboreal pit vipers the mean perch height did not differ significantly. The mean perch height for *T. malabaricus* was 1.56 ± 0.61m (ranged from 0. 60 to 3.35m) and that of *T. gramineus* was 1.48 ± 0.55m (ranged from 0.54 to 3.04m) this could help avoiding the avian predators as very high perch heights has the risk of predations whereas low perch height may affect thermoregulation. Also the males and females of both the species showed no significant difference between the perch heights.

Although the data indicates no significant difference in perch height between the two species and also between the sexes of two species, the vertical heights used by snakes were positively correlated with the body length except for males of *T. malabaricus* which showed a negative correlation. This may have been due to constrains on the available vegetative height in the forest. These findings supported the hypothesis that hygrothermal profile i.e. ambient temperature and humidity might affect the perch height selection during dry and wet seasons, this findings augments that of Shine *et al.* (2005). During the dry seasons attaining higher perches may help to avoid high ambient temperature close to ground level for example Heatwole (1970), suggested that arid zone lizards attain higher perches in hotter weather to avoid high temperatures on the ground. Whereas, during monsoon higher perch heights may be attained for basking. However, this result is primarily based on data of five individuals during both dry and wet seasons and more intensive study is required to interpret this result cautiously. On the contrary there was a significant difference in perch diameter used by males and females of both the species which also showed a positive correlation between body mass and perch diameter. Suggesting that arboreal pit vipers select the twigs/branches depending on their body mass. Thus, heavier arboreal snakes might prefer lower branches (perch height) if the twigs become more slender towards the apex of the tree and the weight carrying capacity of the twig decreases. These assumptions again depend on the type of tree species and the habitat composition.

However, no correlation between body size and perch height (Henderson, 1974) and body mass and twig diameter (Rodda, 1992; Tu *et al.*, 2000) were found in other studies. The analysis of the regions of the branch (distal, apical and middle) inhabited by the arboreal snakes showed that the regions inhabited by the arboreal pit vipers differed significantly; *T. malabaricus* occupied the distal region of the branch followed by middle and apical this could be due suggesting that whereas *T. gramineus* was found to prefer middle region on the branch followed by middle and distal. The preference for distal position by *T. malabaricus* may be mainly to conceal with the branch colour whereas, the preference by *T. gramineus* for middle and apical regions on the branch may be to conceal with the foliage as the coloration of *T. gramineus* will help them to easily conceal with the foliage and thus help avoid predation as well as in for capturing prey. However, few individuals of *T. malabaricus* on middle and apical region of the branch and that of *T. gramineus* on distal region of the branch were encountered, this encounters are possibly due to presence of the prey, but the type of vegetation (bare branches i.e. branches without leaves and thick bushes) will also determine the location of the snake on the branch. The findings of the present study, thus suggest several patterns (i.e. hygrothermal profile, positive correlation of body length with perch height, positive correlation of body mass with perch diameter and regions of branches utilized) play an important role in perch height selection.

Further, *H. hypnale* was occasionally sighted among small herbs exhibiting semi-arboreal habit. The occasional use of arboreal habitat offers a good opportunity for the snake as it might reduce the efforts or energy needed to thermoregulate or search prey. Similar observations are reported by Oliveira and Martins (2001) and Shine *et al.* (2005) for *Bothrops atrox* and *Thamnophis sirtalis parietalis* respectively. Most of the individuals of *H. hypnale* were encountered beneath leaf litter. As discussed earlier the leaf litter temperature is lower than the ambient temperature thus, providing a cool climate. Few individuals were encountered on the bare ground; this may be due to the need for thermoregulation (basking). Reptiles depend on particular components of their habitat to maintain a proper body temperature (Christian *et al.*, 1983; Kearney, 2002; Heard *et al.*, 2004). However, the individuals encountered on the bare ground were always closer to the cover objects. Remaining close to cover objects may help the snake to conceal and avoid detection by predators and to ambush prey. Similar observation is reported by Mullin and Cooper (2000).

Colour

At a broader view two colour patterns were observed amongst the three pit viper species found in Goa. The arboreal species exhibited shades of green whereas the terrestrial species exhibited shades of brown. Green colour patterns in arboreal species renders them cryptic against background of green foliage or branches, whereas brown colouration in terrestrial species provides crypsis against the many terrestrial backgrounds. Lillywhite and Henderson (1993) reported that green colour patterns are predominant amongst arboreal viperid species, particularly in tropical environments.

The study revealed that *T. malabaricus* exhibited different colour patterns during different seasons, few individuals exhibited colour patterns that were only seen during dry seasons. However, this colour changes was related to the colour of the substratum used. Whereas, *T. gramineus* did not show a major change in colour patterns except that, it had bright colouration during wet season and dull colouration during dry seasons again, this colour changes was in terms of the substrate used. On the contrary *H. hypnale* did not show any seasonal variation in colour change however, the colour change was basically dependant on the type of substrate used. Thus, the pit vipers species studied exhibit facultative crypsis, whereby the animal modifies its camouflage response to different backgrounds as the best camouflaged animals are often difficult to be located by the predators.

No sexual dimorphism in colour was observed amongst the three species. However, Shine (1993) mentioned sexual dimorphism in colour in *H. hypnale* which in turn was reported by Taylor (1950). This is difficult to resolve as the sample size and location from which the samples were collected and analysed is not known, on the contrary recent research on a taxonomic revision of the South Asian hump-nosed pit vipers (*H. nepa*, *H. zara* and *H. hypnale*) by Maduwage *et al.* (2009) did not mention any such dimorphism in *H. hypnale*. An ontogenic shift in coloration between juveniles and adults of *H. hypnale* was observed during the study. Such a shift in colouration was also reported by many authors (Wharton, 1960; Carpenter and Gillingham, 1990; Gloyd and Conant, 1990) in some pit viper species, including several within the genus *Agkistrodon* where juveniles, possess yellow tail tips that can be used to attract prey in a display known as caudal luring. Most pit vipers lose their yellow tail coloration as they grow, presumably reflecting a shift from prey that respond strongly to luring (e.g. amphibians and lizards) to those that do not (e.g. mammals and birds; Heatwole and Davison, 1976). Smith (1943) included *H. hypnale* into the genus *Agkistrodon* and has also reported shift in colour from juvenile to adults. However, such a shift in colour in the *T. malabaricus* and *T. gramineus* could not be described due to lack of data.

Reproduction

Sexual Dimorphism in Body Size:

All the three species were sexually dimorphic with females having significantly larger SVL, CL, HDL, HWD, VS and males having more number of CS. Similar observations have been made in *Bothrops neuwiedi pubescens* (Hartmann *et al.*, 2004) and other species of the genus *Bothrops* (Solorzano and Cerdas, 1989; Sazima, 1992; Sazima and Manzani, 1998). Shine (1978: 1994) reported that this is the most common condition in snakes and has correlated this with absence of male - male combat behaviour. However, the male- male combat behaviour in any of the three species studied cannot be commented as such behaviour was not observed during the present study.

morphometric differences varied insignificantly when compared between the three species.

The larger body sizes (SVL) in females may be due to the size dependent fecundity, which provides more space for the reproductive organ and embryos within the body cavity (Shine, 1993). In *H. hypnale* there was a significant positive correlation between body length and litter size. The difference in CL is most probably a result of morphological constrains of the hemipenis. Smith (1943) reported the hemipenis of *T. malabaricus* extended to 12th caudal scale, that of *T. gramineus* to 11th to 12th caudal scale and that of *H. hypnale* to 15th caudal scale. However, the SVL and CL when compared between the arboreal species and terrestrial species, it was noted that arboreal species had longer SVL and CL than terrestrial species. Such a difference in body length between arboreal and terrestrial species may be associated with the arboreal habitat (Pizzatto *et al.*, 2007), as well as problems associated with climbing and physiological necessity for e.g. longer tails might help gravid females to bear their weight on branches by providing a strong hold on the branches during prey capture and other activities. This also explains the difference in tail length between male and females of arboreal species. Many studies (Cadle and Green, 1993; Lillywhite and Henderson, 1993) have suggested elongation in tail and larger body length i.e. decreased in stoutness has resulted from arboreality in snakes.

Larger head length, head width and VS count in females are possibly an adaptation to ingest larger prey. Similar observations has been reported by Shetty and

Shine (2002) and Monteiro *et al.*, (2006) and thus reflect sexual dimorphism in diet (Hartmann *et al.*, 2002 and Martins *et al.*, 2002) as far as prey size is concerned (Houston and Shine ,1993). This also explains the difference in HDL and HDW between arboreal and terrestrial species, as larger HDL and HDW might help arboreal species to prey upon larger prey items such as birds. Zhao and Adler (1993) reported that Mell (1929) suggested that an increased number of scale rows provide greater flexibility, enabling the skin between the scales to stretch over a larger prey items. This is relevant when VS is compared between the arboreal and terrestrial species, however, when compared between sexes of all the three species higher number of VS might facilitate the females to endure larger fecundity. On the contrary, the CS count was higher in males than in females except in *H. hypnale* where females had higher CS count. The higher CS counts in males of arboreal species might be an adaptation to arboreal habitat as during courtship the male has to hold on to the female and also possibly to the twig of the tree and higher CS count might help in stretching the skin of the caudal region, on the contrary, in terrestrial species this possibility does not arise. However, this possibility needs to be examined as the exact mating behaviour of the pit vipers is not known.

The sexual dimorphism in neonates and juveniles of the arboreal species could not be assessed as no juveniles were encountered during the study. However, sexual dimorphism in all the morphometric measures was observed in neonates of *H. hypnale*. The sexual dimorphism in scale count of neonates of *H. hypnale* was not examined due to the difficulty in visibility and counting the scales owing to their small size. However, significant sexual dimorphism was observed in other morphometric measures (SVL, CL, HDL and HDW). Thus, as in adults, neonates of *H. hypnale* can also be differentiated based on their morphometric measures.

The pit viper species studied are viviparous. Since no mating was observed, the exact gestation period and litter size of *T. malabaricus* and *T. gramineus* is not known, the lack of information in literature also makes it difficult to comment on the same. The fact that snakes are secretive and difficult to locate in the field may contribute to the overall lack of information. However, in *T. popeiorum popeiorum* Whitaker and Captain (2004) reported the parturition period between April-May. Khaire (2006) reported the litter size in *T. malabaricus* (in Mahabaleshwar and Goa) to be 4-8 young ones, it also reports that a captive female of *T. gramineus* gave birth to 21 young ones in Matheran (Maharashtra), however this data is based on a single sample.

The data collected from two gravid females of *H. hypnale* kept in captivity and two dead (killed) gravid females collected from the cashew plantations suggest that the litter size varies from 7-9 young ones. The exact mating time is difficult to reveal, as mating was not observed during the present study. However, the data suggest that the gestation period to be approximately 3 to 4 month, but this is difficult to confirm as the exact mating time was not known. Since, the female was captured in the month of January the mating period may be predicted to be somewhere during post monsoon or winter, but it is obvious that firm conclusions cannot be made on the basis of the small sample size and limited quantitative information, however, as discussed earlier this coincides with the shift in habitat from forest to cashew plantation shown by gravid females of *H. hypnale*. Observations during the present study contradicts with that of Khaire (2006) who reported that mating period in *H. hypnale* to be from March to April, as gravid females in the month of January were encountered during the present study and therefore this warrants further study involving radiotelemetry and endocrinological studies related to the duct size in males and vitelogeny in females.

The parturition in *H. hypnale* was found to occur in the month of April- May. This may be due to the fact that the colour of the neonates is different from the adult (grayish) and during the dry seasons this might help the neonates to escape detection by predators. The smaller size of juveniles makes them vulnerable to wider range of predators (Blouin- Demers *et al.*, 2007). Also the onset of monsoon along with the pre - monsoon showers will provide ample of food resources. Thus, easy prey availability will restrict their movement and thus again help in escaping predators and also help in fast growth. Previous studies on snakes show that food intake early in life can significantly influence consequent survival, growth rates, and body sizes (Forsman, 1993; Madsen and Shine, 2000). Gestation can take several months, during which female snakes eat little if at all (Shine, 1980; Seigel *et al.*, 1987; Madsen and Shine, 1993; Gregory and Skebo, 1998; Gregory *et al.*, 1999). Extended starvation combined with heavy expenditure of stored reserves in their offspring leaves females in poor post parturition condition. After giving birth, female snakes must actively forage to rebuild reserves (Madsen and Shine, 1993). Thus, parturition during pre- monsoon period may enable females to obtain prey much more easily as food availability during the rains is usually abundant.

The sex ratio in the litter of both females was female biased. Maternal body temperature during pregnancy affects the scalation traits of male sex more than female sex in a viviparous snake species (Arnold and Peterson, 2002). Such sex differences arising due to incubation temperature may support the evolution of temperature dependent sex ratio (Charnov and Bull, 1977), and facilitate maternal control over offspring sex ratios by nest-site selection or maternal thermoregulation. Although sex-specific rates of mortality are not well documented for snakes, there is evidence that, costs of reproduction may make female-biased mortality the norm for snakes, especially among viviparous species (Madsen and Shine, 1993). Female mortalities were also recorded during the present study. Magnhagen (1991) and Andersson (1994) suggested that reproduction often involve increased risk of mortality for animals. When those risks differ between males and females, the resulting sex-biased mortality is likely to have important demographic, sexual selection and life-history consequences. Also offspring viability is affected not simply by the absolute amount of nutrients allocated to each ovum (Sinervo *et al.*, 1992), but also by slight variations in egg composition. For example, hormone levels in the yolk can modify developmental pathway (Bowden *et al.*, 2000).

Foraging ecology

The pit viper species studied during the present study were ambush (sit and wait) predators and did not show any change in foraging and retreat sites and used crypsis as a foraging strategy. Except for few occasions where *T. malabaricus* and *T. gramineus* were found crossing the road during monsoon, which can also be attributed to mate searching.

Greene (1992) and, Lillywhite and Henderson (1993) suggested that arboreal snakes may remain immobile most of the time, be cryptically colored (brown or green), and often have large eyes in order to feed successfully and avoid predation. Prey acquisition and foraging requirements are thus important cues for snakes when selecting retreat sites. This is especially true for sit and wait predator, since a poor choice may significantly affect their hunting efficiencies (Downes, 1999). In *H. hypnale* it was observed that it remained concealed with the background, tightly coiled and attracted prey by caudal luring. Similar observation was reported by Murthy (1990) in *H. hypnale* and Eskew *et al.* (2009) in eastern cottonmouth snakes.

There was no major difference observed in prey selection except for that the arboreal species preyed upon birds and arboreal reptiles, whereas, *H. hypnale* preyed upon terrestrial reptiles and amphibians. However, during the present study the observations of feeding instances in the field by the pit vipers were very few. Studies (Mao, 1970; Lee and Lue, 1996; Creer *et al.*, 2002) on other tree vipers primarily suggested that they feed on frogs, lizards of the Agamidae, birds, and rodents. The findings of the probable prey items for pit vipers during the study were in accordance with those of Murthy (1990), and Khaire (2006). Feeding trails carried out in captivity revealed that the pit vipers are generalized feeders, however, it was noted that all the three species ignored rodents (common house rat), thus it is very doubtful to comment whether or not these species feeds on rodents in the field.

During the feeding trials it was also observed that the arboreal species avoided large lizard prey. Few studies (Murphy and Campbell, 1987; Campbell and Solorzano, 1992) that has focused on the feeding behaviors of arboreal snakes suggested that the effect of gravity may restrict prey size when feeding from twigs, thus, it is necessary for arboreal snakes to choose smaller prey, grasping dangerous and struggling prey may lead to release it and not being able to relocate it in an arboreal environment. Since choice of prey size is seen in adults, this affirms that juvenile predators will also physically be unable to ingest larger prey, thus, suggesting ontogenic shift in prey size selection. Such size-related shifts may have major ecological implications: for example, prey-size distributions can influence body-size distributions of predators (e.g. Madsen and Shine, 1996) or the degree of sexual dimorphism in mean adult body size or feeding structures (Slatkin, 1984; Houston and Shine, 1993).

The analysis to know whether seasonal changes in encounter rate and distribution of pit vipers is affected by prey abundance revealed that, there was a significant positive correlation between the number of individuals of each species of pit viper encountered and the abundance of prey found during different seasons. This has been supported by studies which show that reptiles like all other predators prefer habitats with high prey abundance (Houston and Shine, 1994; Mullin and Cooper, 2000; Theodoratus and Chiszar, 2000; Blouin-Demers and Weatherhead, 2002; Shine and Sun, 2002; Shine *et al.*, 2002b; Heard *et al.*, 2004; Tsairi and Bouskila, 2004). However, this analysis was restricted to a single study site and year and therefore needs more such estimations to confirm this fact.

Pit tagging

PIT tagging experiments revealed that the pit vipers do not move to very long distances. Also the change in mass was low, the change in mass observed could be attributed to the process of feeding. There was no change observed in the morphometric parameters from the day of release to the day of recapture, suggesting that the growth rate is very low. However, more detail study is required as the sample size and the time period between the release and recapture of the snakes was very less (less than a month) and the data obtained was mainly based on the females, no males were recaptured during the study. The less sample size of the recaptured animals could be due to the fact that pit vipers remain highly camouflaged with the surroundings and hence might have escaped detection, another reason being they might have moved outside the transect due to human disturbances as the transect falls in one of the areas frequently visited by tourists or possibly fell prey to predators. Heatwole (1977) and Pough (1983) suggested that ectothermy is a physiological constrain to behavioral avoidance of disturbance because reptiles are often tied to specific activity periods, habitats or retreat sites.

All this possibilities cannot be ignored, however, advanced technologies (radiotelemetry) is required to know the movement pattern and other details of the snakes. As in PIT tagging one has to rely on recapturing the snake, whereas in radiotelemetry the snakes can be located by the signals broadcasted by the transmitters. Such studies require small sized transmitters as too large transmitters are difficult to implant in these species.

Behavioural Ecology

Behavioural studies reflect that pit viper species spend most of the time waiting in ambush in their habitat. It was observed that amongst all the three species, the individuals moving were encountered during the night, exhibiting nocturnal behaviour. Movement during the night might help these species escape predators, especially avian predators (excluding nocturnal birds). According to Sun *et al.* (1990), snakes remain immobile for hours at a time, only moving from their ambush positions at nightfall. However, the number of individuals sighted moving at night was very less, also the encounter rate of active individuals i.e. individuals with neck forming S-coil and head lying over the body, individuals in foraging position was less during the night as compared to their encounter rate during the day, suggesting that they shift their diurnal activity depending on physical exchange with the environment.

No significant difference was observed between activity patterns of all the three species during day and night. Mushinsky and Hebrart (1977) and Gibbons and Semlitsch (1987) reported that, reptiles may shift between nocturnal and diurnal activity depending on seasonal temperature regimes and reduce activity on cool or cloudy days (Peterson, 1987; Peterson *et al*,. 1993; Nelson and Gregory, 2000). The insignificant pattern can be basically related to prey as at day time, diurnal prey and at night nocturnal reptiles and frogs are available. According to previous studies, reptiles within retreats often adjust their posture or position to exploit thermal gradients in order to regulate their body temperature (Losos, 1987; Huey *et al.*, 1989; Kearney and Predavec, 2000). Relative humidity or moisture (Henderson and Hoevers, 1977; Dalrymple *et al.*, 1991; Daltry *et* *al.*, 1998 b; Sun *et al.*, 2000) may be more important in this respect. There is little published information on how weather fluctuations may affect the activity of tropical reptiles (Brown and Shine, 2002; Henderson and Hoevers, 1977; Gibbons and Semlitsch, 1987).

Mayr (1963) suggested that in different habitats, snakes may exhibit different behaviours which in turn lead to selection for phenotypes that maximize the effectiveness of these behaviours. Thus, the habitat occupied may also play an important role in behaviour of these pit vipers. On one occasion *T. gramineus* and on three occasions *T. malabaricus* were encountered, that remained in resting position on the same location consecutively for four-five days during the full moon day and waning period. Similar observations are made in *Acrochordus arafurae* (Houston and Shine, 1994), *Calloselasma rhodostoma* (Daltry *et al.*, 1998 b). This suggests that on moonlight nights there must be a decrease in activity of the pit vipers, as on illuminated nights moonlight discourages activity as moving snakes become more visible to their prey or predators. The observations also suggests that the pit vipers remain highly concealed with the backgrounds exhibiting an anti predator behaviour. Camouflage as an anti predator behaviour tactics is used by many animals. Conspicuous colour patterns represent the opposite end of the continuum from camouflage and are used by many animals to attract mates and daunt rivals (Andersson, 1994).

It was observed that *H. hypnale* used caudal luring to attract their prey, but such behaviour is impossible in arboreal species as they use their tail to hold on the branch.

Snakes tend to ingest prey from the anterior end (Mehta, 2003), which also occurred in this study. The observations in the field as well as in captivity revealed that all the three species of pit vipers engulfed their prey from the anterior end. If ingestion is attempted tail-first, the direction of scales, limbs, or feathers may impede swallowing (Campbell and Solorzano, 1992) and it can than lead to the death of the snakes. The capture position was mainly at the anterior end (neck and shoulder) and captured their prey successfully after single strike showing a precision in their attack. Capturing prey at the location close to their head could also decrease the risk of retaliation (Mehta, 2003). So, most snakes ingest prey from the head end (Murphy and Campbell, 1987; Brown and Lillywhite, 1992; Campbell and Solorzano, 1992). Thus, suggesting that the capturing site is decided by the pit vipers before they attack their prey and the facial pits of pit vipers must be involved in such a tactic. Snakes may use visual, infrared, chemical and/or tactile cues in the feeding process (Murphy and Campbell, 1987; Ford and Burghardt, 1993).

The pit vipers do not release their prey after striking them on the contrary wait till their prey is immobilized. This may be so because of difficulty in relocating the prey especially for arboreal species. Similar behaviour was also recorded in *Trimeresurus s. stejnegeri* by Tsai (2007). There was a significant positive correlation between the prey size and time taken for ingestion of the prey. This also varied significantly between all the three species studied, suggesting that the time taken for swallowing will increase with increase in prey size.

Phylogenetic Study

The topology of both the NJ and MP phylogenetics trees was in agreement with the already reported findings of (Malhotra and Thorpe, 2004b; Malhotra, *et al.*, 2010). There is no significant change or shift in the positioning of *T. gramineus and T. malabaricus* in the phylogenetic tree of pit vipers. However, there is a potential chance of resolving the position of *H. hypnale* with further extensive study using more number of molecular markers. The 16S rRNA sequences of *H. hypnale* represent exception falling in the group of New world pit vipers. The phylogenetic position of *H. hypnale* is not clear since there are no reports on genetic study of this species in the available literature. This is the first report showing that it is distantly related and indeed genetically very distinct from the other two pit viper species from Goa/Western Ghats. Also the population parameters for *H. hypnale* show low genetic diversity, therefore concentrated efforts are recommended immediately for long term conservation of *H. hypnale* species in Goa.

Threats and Conservation measures

The decrease in encounter rate over the period of this study itself suggests that the pit viper species are under threat. Predation is one of the threats, during the field study there was increase in sightings of peacock over the years in some of the transects and the same was reported by the locals; peacock being one of the predator, increased population of peacock may increase the risk of predation. However, predation is a natural phenomenon and therefore unless census survey of predators is carried out one cannot directly link predation to the extinction pressure faced by the species. Proper scientific investigation as to why there is an increase of a particular predator species can help state conservation measures.

The present study revealed that the pit viper species found in Goa faces tremendous anthropogenic pressure. Human activities have modified natural habitats in many ways. The most dramatic changes involve widespread degradation of entire areas, such as a shift from forest to agricultural use (kumeri plantation). Removal of feral plants in the forest by the locals for domestic use may lead to degradation of the habitat. Thus, minimizing the available habitat for arboreal species. Most of the present study sites (MWS, NWS and CWS) consist of human habitation and the villagers residing in these sanctuaries are dependent on the forest resources for their daily livelihood. However, increasing agricultural land (especially cashew plantation) will favour the *H. hypnale* species as they use this habitat during post monsoon to summer which coincides with the season of cashew crop, but at the same time it will put more pressure on this species as the locals kill these individuals out of fear as soon as they are encountered. Such phenomenon is not uncommon in some parts of Goa, especially in places such as Sattari and Sanguem, and it being the gravid females which move to cashew plantations killing of these females could lead to a decline in the population of *H. hypnale*. Thus, the impact of this kind of direct killing on natural populations is difficult to evaluate, because the degree to which anthropogenic mortality affects population viability depends on a complex series of factors.

The absolute number of animals killed is obviously important, but population-level impacts will also depend on the kinds of animals killed (e.g. male vs female, adult vs juvenile, reproductive vs non-reproductive) as well as the timing of mortality. At the same time encroachment will affect the habitat of *T. malabaricus* and *T. gramineus*. However, reptiles might be especially vulnerable to human disturbance because their limited mobility restricts movement to less disturbed areas. Many animals react to people as potential predators, and human evasion may result in home range displacement (McLellan and Shackleton, 1988), disruption of foraging (Gander and Ingold, 1997) and reduced reproductive success (Safina and Burger, 1983; Giese, 1996). Dodd (1987) and, Caughley and Sinclair (1994) suggested, for many animal populations living in densely-settled areas, direct killing by humans may be a significant component of the overall effect of human activities on wild populations, because this aspect of the interaction between humans and wildlife is unlikely to be as important overall as broader-scale processes such as habitat destruction. Thus, a conscious effort of educating the workers, on the conservation importance of these reptiles is required. Effort to rehabilitate the human residing in the sanctuary will also help in reducing the anthropogenic pressure on the forest resources; a successful effort has already been made at Bhagwan Mahaveer Wildlife sanctuary (Nandran village) and the same should be implemented in other protected areas.

Analysis on the effect of tourism on the encounter rate of pit vipers revealed that the increase in tourism over the period of the present study (2005-2009) has affected the encounter rate in the transects frequently visited by the tourists. There was a significant impact of tourism in CWS and BWS, and this impact is considered to be throughout the year as the transects selected for this study were visited by the tourist throughout the year. However, the impact of tourism on encounter rate of pit vipers was not significant at BMWS, this could be possibly because all the transect in BMWS that were visited by tourist were selected for the study, if this study was to be restricted to the transects which were frequently visited than the result would might have been significant. Such a threat can be prevented by restricting the tourism activities only to certain areas and avoiding tourism in core areas of the sanctuaries. Since the major area at BWS is occupied for tourism, probably implementing a better management plan, thus avoiding the regions were wild species exists in greater numbers and restricting tourism activities only to particular area will aid in conservation of these species.

The presence of roads, natural streams and manmade barriers in the sanctuaries also pose a considerable threat, especially by restricting the movement of the pit viper species. The reports of low road kill might be possibly due to quick response of the predators on the killed pit vipers. Though no much road kills have been reported during the present study, yet the vehicular disturbances will also affect the species movement. Mader (1984), Reh (1989) and Fehlberg (1994) suggested that roads constitute behavioral barriers to animal movement may effectively fragment populations in otherwise continuous habitat. Shine *et al.* (2004) suggest that the proliferation of roads, including small gravel tracks and larger highways may directly affect snake behaviors and mating systems. Roads can therefore act as significant barriers to gene flow, which can ultimately reduce the overall genetic diversity of populations (Epps *et al.*, 2005). Thus, minimizing the barriers especially man made barriers such as small trenches and compound walls in the sanctuary will help in free movement and thus gene flow of these species.

Habitat fragmentation due to mining activities around the protected areas is the immediate threat to this species. Goa is a small state and mining is a major source of income for the state, most of the mining leases are around the protected areas, thus it has become very difficult to protect the habitat of this species. It is, therefore, important to create awareness among the communities to protect the habitat in order to protect these species. The government agencies (policy makers) play a vital role in directly conserving the habitat of the species, which in turn can aid in the indirect conservation of these species.

Conclusion

It seems evident from the present study that pit viper species are habitat specific. The proportion of habitat available, including abiotic factors, such as seasonal changes in temperature and humidity, prey availability within the habitat have influence on the distribution and abundance of these snakes.

The pit vipers in Goa especially *H. hypnale,* although highly adapted to anthropogenic habitat (Cashew plantation) is facing tremendous anthropogenic pressure, as shift of *H. hypnale* to cashew plantation coincides with the peak season of cashew. Besides this, all the three species of pit vipers also faces tremendous pressure due to habitat disturbance and habitat loss as a result of human activities. The findings of haplotype analysis of *H. hypnale* showed very low haplotype diversity which is of a great concern as low genetic diversity may result in the homogenous population of *H. hypnale* making it vulnerable to extinction.

Though, pit vipers are not charismatic species as tigers, it can serve as an important indicator of habitat degradation and can be used for ecological monitoring since they are habitat specific. Thus, conservation of these species should be initiated.

Three species of pit vipers are found in Goa viz. *Trimeresurus malabaricus, Trimeresurus gramineus* and *Hypnale hypnale* Out of these three species *T. malabaricus* is endemic to the Western Ghats, *T. gramineus* is endemic to Peninsular India and *H. hypnale* has been recorded mainly from the southern part (up to about 16^0N) of the Western Ghats and Sri Lanka. All the three species reported in Goa are Schedule IV animals and falls under the category of Lower risk- Near threatened. The Western Ghats of India is one of the 34 biodiversity hotspots in the world. Its biodiversity is under threat due to deforestation the studies on their ecology have not been conducted in detail. Thus, this study on ecology of pit vipers was undertaken to address this gap in information and to device strategies for their conservation. Goa (3702km2) is a small state along the central west coast of Indian peninsula and encompasses about 2% area of Western Ghats.

Studies on ecology of pit vipers are restricted to countries outside India. No precise ecological studies have been carried out in India with special reference to Goa, except a few studies which have focused on the diversity and distribution and phylogeny of pit vipers in India. Studies on ecology, distribution, abundance and phylogeny are deficient with special reference to Goa region. Am attempt was made to study the habitat ecology and habitat preference, color variations, reproduction, foraging ecology, behavior of pit vipers. The phylogenetic relationship of pit vipers found in Goa was also analysed and their threats were assessed and conservation measures are suggested.

The present study was conducted in the five protected areas of Goa and in cashew *(Anacardium occidentale)* plantations within and adjoining to these areas. Surveys and sampling was conducted using band transect method on a predetermined paths or roads (2500x20 m) from June 2005 to June 2009. All pit vipers encountered during the present study were identified up to species level. Habitat ecology and habitat preference (macrohabitat and microhabitat) in pit vipers were studied. Forest types were classified based on Champion and Seth (1968). Seasonal changes in habitat utilization were also assessed. Colour change exhibited in all the three species during different seasons and the influenced of substrate and physical environment on colour change were assessed. Sexual dimorphism in colour of pit vipers was also analyzed.

Reproductive study on all the three species was carried out mainly based on field observation. To study foraging ecology prey items were identified based on field observations. Feeding trials were carried out in captivity to identify the preference for prey. Adaptive cluster sampling method was carried out to know prey availability for *H. hypnale* during different seasons. The behavioural study was also carried out. Feeding behaviour was observed in detail and analyzed precisely in captivity.

Threats to pit vipers in all the study sites were assessed by local surveys and field observations. Potential predators of pit vipers were recorded. Threats from tourism was assessed by studying and comparing encounter rate of pit vipers in the transect frequently visited by tourists. Data on number of tourist visiting the transect was procured from Forest Department, Govt. of Goa.

The PIT tagging experiment was carried out on two species (*T. gramineus* and *H. hypnale*). Phylogenetic studies were carried out at CCMB (LaCONES). High molecular weight DNA was isolated using conventional Phenol Chloroform method. DNA was quantified using spectrophotometer and in 0.8% agarose gel. Mitochondrial genes (Cytochrome b and 16 S) were used for the study.

The study confirmed the presence of three species of pit vipers in Goa viz, *T. malabaricus, T. gramineus* and *H. hypnale.* The distribution and abundance of all three species of pit vipers varied as their habitat-use was different. The remarkable change in the shift in habitat from forest to cashew plantations during post monsoon, summer and winter by *H. hypnale* was seen during the present study. The colour variation is seen in different seasons. The pit vipers remain highly camouflaged with the substrate they use. Sexual dimorphism in body size was observed in all the three species of pit vipers. It was observed that the gestation period in *H. hypnale* coincides with the shift from forest to cashew palpations. It was observed that seasonal prey abundance influenced the seasonal encounter rate of *H. hypnale.* Phylogenetic study revealed that pit vipers from Goa show similarity with other pit vipers but are genetically distinct. *Hypnale hypnale* also showed similarity but was distinct from *Trimeresurus* group.

A threat such as human encroachment, ecotourism, presence of roads and manmade trenches in the sanctuary and habitat loss was recorded during the present study.

It seems evident from the present study that pit vipers species are habitat specific and abiotic factors within the habitat such as seasonal changes in temperature and humidity, have influence on the distribution of these snakes. Hence, the protection of habitat is an important aspect in conservation of these species.

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APPENDIX

Appendix 1: Associated floral diversity in the study area.

Scientific name	Local name
Abrus precatorius	kati, gunji
Abutilon persicum	ran petari
Acacia catechu	khair, babhal(m)
Acacia odoratissima	kali-siras
Acacia paniculata	kinai
Acacia pennata	Babul(m) samko (k)
Actinodaphne angustifolia	pisa
Adhatoda zeylanica	adulso
Adina cordifolia	Edu,hedu
Albizia chinensis (rare)	Udal,udel(k),laeli(m)
Albizia lebbeck	siras (k), chinchola(m)
Albizia odoratissima	Kali-siras(k), siras (m)
Aleurites moluccana	akrut
Alseodaphne semicarpifolia	rani (k)
Alstonia scholaris	satvin, santon
Anacardium occidentale	kaju(m,k)
Aporosa lindleyana	sal
Argyreia involucrata	-
Bauhinia wahilli	mavli
Bischofia javanica	boke
Bombax ceiba	vadli savar
Bombax malabaricum	Savar
Bridelia retusa	kamte asan (k), asana (m)
Bridelia retusa	kamte asan
Bridelia retusa	katekavach
Butea monosperma	palas (m)
Butea parviflora	Phulsum(m)
Calycopteris floribunda	uski
Canthium dicoccum	tupa, ansul (m), ursul (k)
Careya arbora	kombyo (k), kuba, kumbia (m)
Carvia callosa	-
Caryota urens	fish tail palm, birlomad
Cassia fistula	balo (k),baya (m), bohava(m)
Dalbergia latifolia	shisham (m), siso (k)
Dalbergia sissoo	Sisva,siso
Erythrina indica	pongaro
Erythrina stricta	pangara (m)
Eucalyptus globulus	niligiri, phirangi methi (m)
Eugenia stocksii	ran-jambhul
Ficus exaperata	karvat
Garcinia indica	bhinda (k), kokum(m)
Gnetum ula	Makad-gangoli

Gouania microcarpa(c?)	shinarbali
Grewia abutilifolia	khar phulsa
Grewia hirsuta	-
Grewia tiliaefolia	dhaman
Helicteres isora	kivon
Holarhena antidysenterica	kudo (k), kuda (m)
Ixora coccinea	podkali (k), pendgul (m), pitkoli, pitioli
Lagerstroemia lanceolata	naram (k), nana (m)
Lagerstroemia parviflora	nano (k), donda, lenda(m)
Lagerstroemia speciosa	Taman (m), sotulari(k)
Lantana camara	ghanari,tantari
Leea indica	jino
Sapium insigne	Uro(k),dudla(m)
Saraca asoca	asok (k), jasundi(m)
Spondias acuminata	ran-ambado
Strychnos nux-vomica	kajro
Syzygium heyneanum	bedas (m)
Tabernaemontana heyneana	Nagil-kudo, kudo
Tectona grandis	saylo
Terminalia alata	asan
Terminalia crenulata	ain (m)
Terminalia tomentosa	matti
Xylia xylocarpa	jamba,verul(m)

Appendix 2: Associated faunal diversity in the study area.

English Name	Scientific Name	Local Name in Marathi (m) and Konkani (k)
Bear, Sloth	*Melursus ursinus*	Asval (m,k), Vashel
Boar, Indian Wild	*Sus scrofa*	Ran dukkar(m),ran-dukor(k)
Cat, Grey Jungle	*Felix chaus*	Baul(m,k),bagoda(m),ranmanzar(m), baul mazor
Civet, Small Indian	*Viverricula indica*	Jowadi manjar (m),javate(k), Katandoor
Civet, Common Palm or Toddy Cat	*Paradoxurus hermaphroditus*	Ud manjar (m), katanor (k),katandoor
Deer,Barking or Muntjac	*Muntiacus muntjak*	Bhekad,bhekro,bakro
Deer, Mouse	*Tragulus meminna*	Pisori, pisay
Deer,Spotted or chital	*Axis axis*	Chital, haran
Gaur	*Bos gaurus*	Gaviya(m),gawa(m),gavoreddo(k)
Hare, Indian or Blacknaped	*Lepus nigrocollis*	Sasa(m),saso(k)
Langur,Common	*Presbytis entellus*	Wanar(m),
Bandicoot Rat	*Bandicota indica*	Kohinoor,Koloundir
Common House Rat	*Rattus rattus*	undir
Leopard	*Panthera pardus*	Karda(m), Bibto-vag (k)
Leopard-cat	*Felis bengalensis*	Wagati(m,k), vagati
Loris,Slender	*Loris tardigradus*	Lajwanti (m),van-anas (k), van manos
Macaque,Bonnet	*Macaca radiata*	Makad(m), makar(m),macod(k),khete.
Mongoose, Common Grey	*Herpestes edwardsi*	Mungoos,mangos
Mouse,Little Indian Field	*Mus booduga*	Undir(k)
Pangolin,Indian	*Manis crassicaudata*	Manzar(m), thiryo (k), khavle manjar
Porcupine, Indian	*Hystrix indica*	Sheval,salendra,sal
Sambar	*Cervus unicolor*	Sambar(m), miru(k),meru
Squirrel, Common Giant Flying	*Petaurista petaurista*	Kotikar(m),puk-mazor(k),udpaco
Boa,Common Sand	*Eryx conicus*	Malun,oon
Red Sand Boa	*Eryx johni*	Malun(k), don ton
Calotes, Common	*Calotes versicolor*	Sherdo(k)
Calotes, Forest	*Calotes rouxi*	Shedo(k)
Chameleon, Indian	*Chamaeleon zeylanicus*	
Cobra, Common	*Naja naja*	Nag(k), paro(k)
Cobra, King	*Ophiophagus hannah*	
Crocodile, Indian mugger	*Crocodylus palustris*	Mangay(k), magar(k), susar(k)
Gecko Dwarf	*Cnemaspis sp*	
Gecko,Banded	*Cyrtodactylus dekkanensis*	
Gecko, Bark	*Hemidactylus leschenaulti*	
Gecko,Brooke's	*Hemidactylus brooki*	Pal(k)
Gecko,Southern Forest	*Dravidogecko anamallensis*	
Gecko,Southern House	*Hemidactylus frenatus*	Pal(k)
Gecko, Termite Hill	*Hemidactylus triedrus*	

eelback, Beddome's	*Natrix beddomei*	Yevale (k)
eelback,Checkered	*Natrix piscator*	Yevale(k)
eelback, Green	*Macropisthodon plumbicolor*	Yavale(k)
eelback, Striped	*Amphiesma stolata*	
rait, Common	*Bungarus caeruleus*	Kaner(k),corret
izard, Fanthroated	*Sitana ponticeriana*	
izard, Flying or Draco	*Draco dussumieri*	Shedo(k)
Ionitor, Common Indian	*Varanus bengalensis*	Gar(k), sardook(k)
ython, Indian	*Python molurus*	Sardook(k),har(k),azgar(k)
ea Snake, Valakadiyan or Iooknosed	*Enhydrina schistosa*	
hield-tail Ocellate	*Uropeltis ocellatus*	
kink, Common	*Mabuya carinata*	Shirli (k)
kink, Little	*Mabuya macularia*	Shirli (k)
kink, Snake	*Riopa punctata*	
nake, Blind or Beaked Worm	*Typhlina acutus*	Telyo (k)
nake, Blind, or Common vorm	*Typhlina bramina*	Telyo(k)
nake, Cat, or Indian Gamma	*Boiga trigonata*	Manjra sap
nake,Ceylon Cat	*Boiga ceylonensis*	
heild Tail Snake	*Plocturus canaricus*	
Iobnosed Sea Snake	*Enhydrina schistosa*	Marke, towai
nake, Common Kukri Banded?)	*Oligodon arnensis*	Kaner (falsly)
nake, Common Wolf	*Lycodon aulicus*	Pasko (k),pasco
nake,Dog-faced Water	*Cerberus rhynchops*	Kusdo (falsely)
nake,Fasciolated Rat or Banded Racer	*Argyrogena fasciolatus*	
nake, Forsten's Cat	*Boiga forsteni*	Manjra sap
nake,Golden Tree or Flying nake	*Chrysolpelea ornata*	-
nake,Rat.or dhaman	*Ptyas mucosus*	Dhivad(k)
nake,Russell's Kukri	*Oligodan taeniolatus*	Kaner (falsely)
nake,Tree or Common Indian Bronzeback	*Dendrelaphis tristis*	nanati
nake, Trinket	*Elaphe helena*	divod
nake,Whip or Common Green or Vine Snake	*Ahaetulla nasutus*	haryali
Tortoise,Pond	*Geomyda trijuga*	Kasav(k)
Viper, Bamboo Pit	*Trimeresurus gramineus*	Chapte(k)
Viper malabar Pit	*Trimeresurus malabaricus*	
Viper, Russell's	*Vipera russelli*	Ghonus(k), agio-maindo(k),kusdo
Viper, Saw-scaled	*Echis carinatus*	phurse
Coral Snake	*Callophis sp?*	Rakt mandol
Bulbul, Greyheaded	*Pycnonotus priocephalus*	
Bulbul,Redvented	*Pycnonotus cafer*	Pitkoli(k)
Bulbul, Redwhiskered	*Pucnonotus jocosus*	Buchudi(k)
Bulbul,Rubythroated Yellow	*Pycnonotus malanicterus*	buchundi

Bulbul,Whitebrowed	*Pycnonotus luteolus*	
Bulbul, Yellowbrowed	*Hypsipetes indicus*	
Bunting, Blackheaded	*Emberiza melanocephala*	
Bustard-quail, Common	*Turnix suscitator*	
Buzzard,Ctrested Honey	*Pernis ptilorhyncus*	
Buzzard-eagle, White-eyed	*Butastur teesa*	
Chloropsis, Goldfronted	*Chloropsis aurifrons*	
Chloropsis, Jerdon's	*Chloropsis cochinchinensis*	
Cormorant,Little	*Phalacrocorax pygmaeus*	
Coucal	*Centropust sinensis*	Kucho-kombod(k)
Crow-House	*Corvus splendens*	Kavlo(k)
Crow,Jungle	*Crovus macrorhynchos*	Dom-kavlo(k)
Cuckoo, Indian	*Cuculus micropterus*	
Dove, Spotted	*Streptopelia chinensis*	Kavdo(k)
Drongo,Ashy	*Dicrurus leucophaeus*	
Drongo, Black	*Dicrurus adsimilis*	
Drongo, Bronzed	*Dicrurus aeneus*	
Drongo, Large Racket- tailed	*Dicrurus paradiseus*	
Drongo,Whitebellied	*Dicrurus caerulescens*	
Drongo-Cuckoo	*Surniculus lugubris*	
Eagle,Black	*Ictinaetus malayensis*	Ghon(k),ghar
Eagle,Crested Serpent	*Spilornis cheela*	
Eagle,Peninsular Serpent	*Spilornis cheela melanotis*	
Eagle,White bellied Sea	*Haliaeetus leucogaster*	
Eagle-owl, Forest	*Bubo nipalensis*	Gugh(k)
Egret,Cattle	*Bubulcus ibis*	Balar(k),baglo
Egret,Large	*Ardea alba*	Balar(k)
Dove, Rufous Turtle	*Streptopelia orientalis*	
Egret, Smaller	*Egretta intermedia*	
Falcon, Shahin	*Falco peregrinus*	
Flowerpecker, Plaincoloured or Nilgiri	*Dicaenum concolor*	
Flowerpecker,Thickbilled	*Dicaeum agile*	
Flowerpecker, Tickell's	*Dicaeum erythrorhynchos*	
Flycatcher, Blacknaped	*Hypothymis azurea*	
Flycatcher, Blacknaped Monarch	*Monarcha azurea styani*	
English Name	Scientific Name	Local Name
Flycatcher,Bluethroated	*Muscicapa rubeculoides*	
Flycatcher,Brown	*Muscicapa latirostris*	
Flycatcher Brownbreasted	*Muscicapa muttui*	
Flycatcher, Greyheaded	*Culicicapa ceylonensis*	
Flycatcher,Paradise	*Terpsiphone paradisi*	
Flycatcher redbreasted	*Muscicapa parva*	
Flycatcher, Tickell's Redbreasted Blue	*Muscicapa tickelliae tickelliae*	
Flycatcher, Verditer	*Miscicapa thalassina*	
Flycatcher, whitebellied Blue	*Muscicapa pallipes*	
Flycatcher, Whitebrowed Blue	*Muscicapa supercilaris*	

Flycatcher-Shrike,Pied	*Hemipus picatus*	
Frogmouth,Ceylon	*Batrachostomus moniliger*	
Goshawk, Crested	*Accipiter trivirgatus*	
Harrier, marsh	*Circus aeruginosus*	
Hawk-cuckoo,Common	*Cuculus varius*	
Hawk-eagle,Crested	*Spizaetus cirrhatus*	
Hawk-eagle,Rufuoubellied	*Hieraaetus kienerii kienerii*	
Hornbill,Great Pied	*Buceros bicornis*	Wayre(k)
Hornbill, Indian Pied	*Anthracoceros malabaricus*	Wayre(k)
Hornbill, Malabar Grey	*Tickus griseus*	valeru
Hornbill, Malabar Pied	*Anthracoceros coronatus*	
Myna,Jungle	*Acridotheres fuscus*	Salori(k)
Owl,Barn	*Tyto alba*	Ghubad(k)
Owl,Collared Scops	*Otus bakkamoena*	
Owl,Great Horned,or Eagle-Owl	*Bubo bubo*	Guch(k)
Owl,Mottled Wood	*Strix ocellata*	
Owl,Scops	*Otus scops*	Natuk(k)
Owlet,Barred	*Glaucidium radiatum*	
Owlet, Spotted	*Athene brama*	Natuk(k)
Parakeet, Blossonheaded	*Psittacula cyanocephala*	Kir(k), popat(k)
Parakeet, Bluewinged	*Psittacula columboides*	Kir(k),popat(k)
Parakeet,Roseringed	*Psittacula krameri*	Kir(k),popat(k)
Peafowl, Common	*Pavo cristatus*	Mor (k)

Appendix 3- Data sheet

Name of the Sanctuary: ________________ **Transect name:** __________

Date: __________ **Starting time:** ___________

Ending time: _____________ **Species:** _________________

Altitude: ______________________ **Latitude:** ________________

Longitude: ____________________ **Temperature:** ____________

Humidity: __________ **Tree species:** _____________

Perch Height: ___________ **Perch Diameter:** __________

Activity: ________________ **Day/Night:** _____________

Sex: M/F **Colour:**_______________

Morphometric data:

S: _______ **CS:** _________

L: _______ **SVL:** ________

W: _______ **HL:** ________

L: ________ **BM:** ________

Gravid/Non-gravid: ___________

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Habitat preference of pit vipers along the western ghats (Goa)

N Sawant and S K Shyama

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The state of Goa is located along the central-west coast of India, lying between latitude 14°51' to 15°48' N and longitude 73°41' to 74° 20' E. There are three main physical divisions viz. the mountainous region of the Sahyadris in the East, the middle level plateaus in the centre and the low-lying river basins with coastal plains. The portion of the Western Ghats lying in Goa (The Sahyadris) has an area of about 600 sq.Km. and an average elevation of 600 meters. The important vegetation of the range include tropical wet evergreen forests, tropical moist deciduous forests, tropical dry deciduous forests, scrub jungles, montanne sub-tropical forests and wet grasslands. Due to its mountainous character, often characterized by steep slopes that make part of it relatively inaccessible, the range has remained undisturbed for much of human history. Partly for this reason and also because of the unique ecosystem it represents, the Western Ghats today are acknowledged to be one of the 'hotspots' of biological diversity and endemism in the world. Six species of pit vipers have been reported from Western Ghats[1]. These pit vipers, except *T. graminius*, are endemic to Western Ghats. Most of them become very active in the evening; during day they remain coiled on a branch [2]. *H. hypnale* is both terrestrial and arboreal in its habit often ascending low bushes in the forest [3].

Pit-vipers belong to the family Viperidae and sub-family Crotalinae. Three species of pit-vipers viz., Malabar pit-viper (*Trimeresurus malabaricus*), Bamboo pit-viper (*Trimeresurus gramineus*) and Hump Nosed pit-viper (*Hypnale hypnale*) are known from Goa, of which two (*T. malabaricus, H. hypnale*) are endemic to Western Ghats. However very little information is available on ecology of these three species. To address this lacuna in our contemporary knowledge the present study was undertaken in 5 sanctuaries in Western Ghats range in the State of Goa Viz. Mhadei wildlife sanctuary, Mollem wildlife sanctuary, Bondla wildlife sanctuary, Netravali wildlife sanctuary and Cotigao wildlife sanctuary of Goa to investigate the habitat preference of the above three species in the wild.

Intensive survey on foot was carried out during Jan to Dec 2005 in the Western Ghat region of Goa specially the sanctuaries mentioned above, Netravali wildlife sanctuary and Cotigao wildlife sanctuary Bondla wildlife sanctuary, Mollem wildlife sanctuary, Mhadei wildlife sanctuary and the possible habitats of pit vipers were recorded. Locality coordinates were obtained by hand held Geographical Positioning System (GPS). Altitude and temperature were recorded using altimeter and mercury thermometer respectively. Specimens were picked up with the wooden stick. Their morphometric measurements were recorded using transparent plastic tube and Identification of these specimens up to the species level was done following the methodology of Smith [1] and Daniel [4]. Habitat preference of vipers was studied by direct observation of the places where they occur.

The sites selected for the present study viz., Bondla wildlife sanctuary, Mollem wildlife sanctuary, Mhadei wildlife sanctuary, Netravali wildlife sanctuary and Cotigao wildlife sanctuary has three types of vegetation viz. tropical moist deciduous, tropical dry deciduous and semi evergreen type of vegetation. Generally these areas fall at an altitude ranging from 45mt msl to 600mt msl (from South to north) and the temperature usually fluctuates between 15^{0}C to 30^{0}C. *T. malabaricus, T. gramineus and H. hypnale* were encountered in the study site. The species of pit vipers and their numbers found in all the five different sites of the present study are indicated in Table. 1. Out of the three species, *T. malabaricus and H. hypnale* were not found in Bondla wild life sanctuary. All the pit-vipers were mostly encountered in these areas during the monsoons and rest of the season they usually rest near moist places. Pit-vipers prefer the close proximity of their prey as their habitats.

During the survey conducted from Jan 2005 to December 2005, it was observed that *T. malabaricus and T. gramineus*, rest for most of the day hours but they become active at night and also found feeding at night exhibiting a nocturnal behavior. Similar observations were made by Whitaker [2] and Murthy [3] in their studies on pit-vipers in the Western Ghats of Maharashtra state.

T. malabaricus closely resembles the Bamboo pit viper in their structural form. Like most vipers, it has a triangular head and a narrow neck. It has brownish coloration, sometimes having darker brown or greenish speckles over the body. *T. malabaricus* are common in altitudes ranging from 700m – 2300 m [3]. However in our study areas we have encountered this species at low altitude ranging from 200m to 600m. A total of around 20 individuals of this species were noted in the selected areas (Table I) ranging in size from 520mm to 900mm. They were usually found in areas of dense vegetation having moist surroundings harboring on large rocks and sometimes on small shrubs. During monsoons they were often found resting in the roofs of old houses or in the drier places in the tree crevices during the day hours.

Table I: Number of pit viper species encountered in selected sites in Goa during day and night hours.

Viper sps.	No. of species encountered										
	NWS		MWS		BMWS		CWS		BWS		Total
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	No.
T. malabaricus	—	2	3	5	5	—	1	4	—	—	20
T. gramineus	2	4	—	—	—	1	1	1	1	1	11
H. hypnale	2	1	2	1	5	2	4	2	—	—	19

NWS Netravali Wildlife Sanctuary ; MWS Mhadei Wildlife Sanctuary
BMWS Bhagwan Mahaveer Wildlife Sanctuary; CWS Cotigao Wildlife Sanctuary
BWS Bondla Wildlife Sanctuary

T. gramineus has slightly keeled scales, wide triangular head, thin neck and is green dorsally. This species resemble green whip snake in their coloration but can be differentiated from them due to the presence of a triangular head. In our study area, we have encountered altogether 11 nos. of individuals of this species from Jan to Dec 2005 (Table I) ranging in length from 380mm – 440mm. They are strictly arboreal and were encountered in all the selected areas of study where the vegetation is mostly moist deciduous to semi evergreen to evergreen. Although Mhadei wildlife sanctuary harbors all the favorable climatic and vegetational requirement for this species, we could not found them during the present study. *T. gramineus* prefer cool thick vegetation near stream edges, bamboo and other jungle foliage.

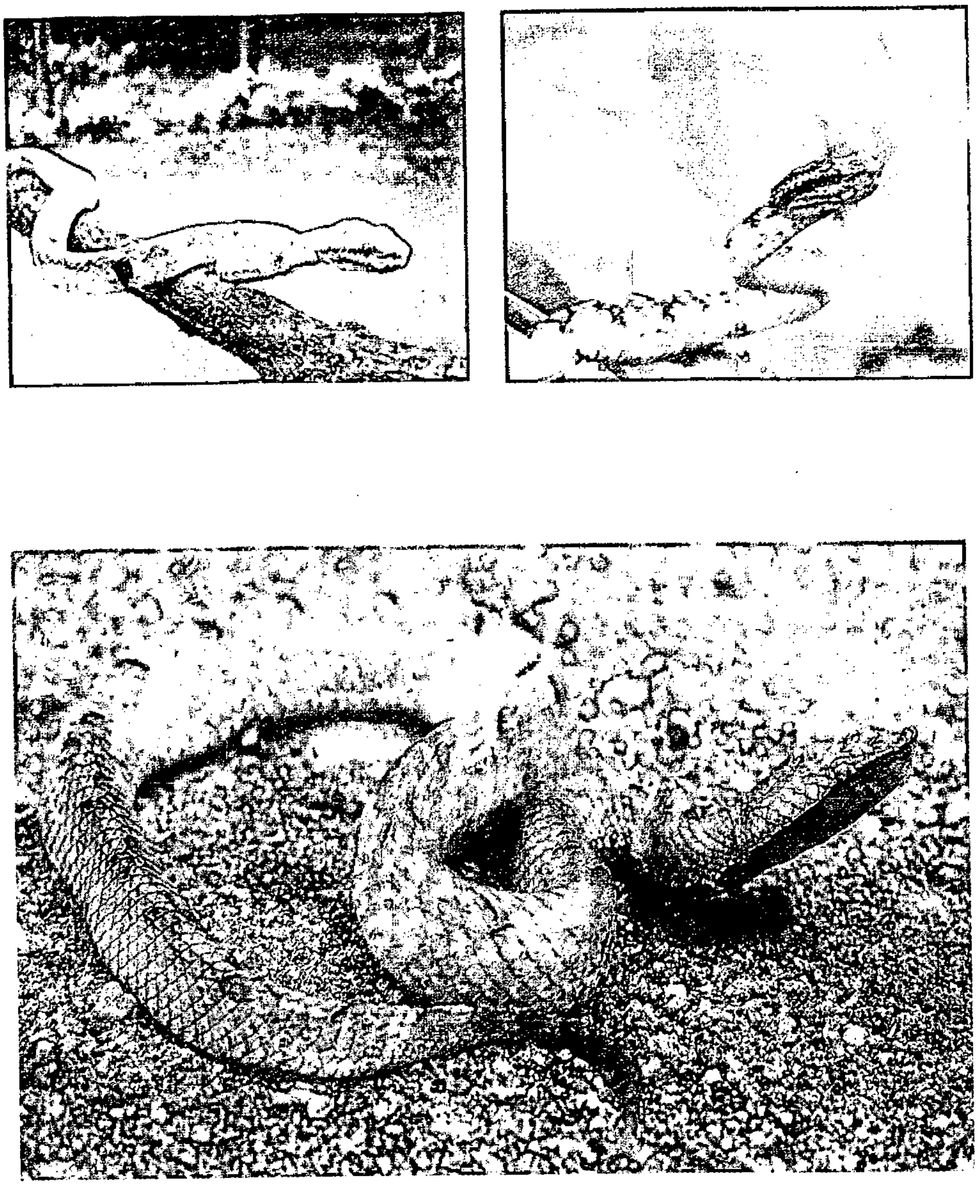

Figure : (Top left) Bamboo pit viper (*T. gramineus*);
(Top right) Malabar pit viper (*T. malabaricus*),
(Bottom) Hump nosed pit viper (*H. Hypnale*)

H. hypnale is a small snake with stocky body, short tail and keeled scales. Snout is acutely pointed and turned up at the end with enlarged scales on the head. It is grey or brown dorsally, heavily powdered or mottled within dark brown and with large ovate dark brown lateral spots and pink tail [2]. A total of 19 individuals of *H. hypnale* were encountered with an average length of 410mm – 460mm. *H. hypnale* was found resting either under the stones or under roots of small shrubs. They were seen predominantly residing in the dry leaves in areas harboring large number of their preys such as skinks, small frogs and small toads and were seen to feed on these preys. These observations are in accordance with those of Murthy [3]. The juveniles were seen feeding on very small sized preys.

Often we found that all these pit-vipers remained camouflaged against their background and could be located only with intense search and observation. *T. Malabaricus* and *T. Gramineus* were often encountered while crossing the road during night hours and got killed accidentally by the passing vehicles. During the survey in the month of December in areas of cashew plantation in the site of our study area, we observed most of the *H. hypnale* resting under the roots of the eupatorium bushes in this area. These pit-vipers were often killed by labourers by fear whenever encountered. Therefore, public awareness is urgently required to conserve these endemic species.

From the present investigations we may conclude that *H. hypnale* prefer terrestrial habitat and other two species viz *T. malabaricus and T. gramineus* prefer arboreal habitat, all these pit-vipers are nocturnal in habit.

Summary :

Vipers are classified into two broad groups, viz., true vipers and pit-vipers , on the basis of presence or absence of a facial pit. Pit-vipers belong to the Family Viperidae and sub-family Crotalinae. Majority of the pit vipers exhibit nocturnal behavior and become very active during night hours. In the present study habitat ecology of the three species of pit vipers viz., Malabar Pit Viper (*Trimeresurus malabaricus*), Bamboo pit-viper (*Trimeresurus gramineus*) and Hump Nosed pit-viper (*Hypnale hypnale*) from wildlife sanctuaries of Goa (Western Ghats) was undertaken. Out of these three species, *T. malabaricus and H. hypnale* are endemic to Western Ghats. However, very little information is available on ecology of these three species. Hence, the habitat preference of the above three species in the wild, their ecology with respect to the locality and morphometric observations was undertaken.

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Distribution and abundance of pit vipers (Reptilia: Viperidae) along the Western Ghats of Goa, India

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Author Contribution: NSS and TDJ have contributed in the field work and writing of the manuscript. SKS contributed in the final editing of the manuscript.

Abstract: The distribution and abundance of pit vipers in the Western Ghats namely *Trimeresurus gramineus* (Bamboo Pit Viper), *T. malabaricus* (Malabar Pit Viper) and *Hypnale hypnale* (Hump-nosed Pit Viper) was investigated in five wildlife sanctuaries of Goa from 2005 to 2009. Seasonal day-night data was collected based on band transect methods. All the pit viper species showed specific habitat preferences and their abundance changed with season. They were most abundant during monsoon. *H. hypnale* extended its range to the adjoining cashew plantations during the post monsoon and winter.

Keywords: Habitat preference, *Hypnale*, seasonal variation, *Trimeresurus*

INTRODUCTION

Goa (14°51'-15°48'N & 73°41'-74°20'E) is a maritime state along the central west coast of Indian peninsula. The Western Ghats of India is one of the 34 biodiversity hotspots in the world (Myer et al. 2000). Goa (3702km^2) occupies about 2% area of Western Ghats (Joshi & Janarthanam 2004) and its biodiversity is under threat due to deforestation (Myer 1990; Menon & Bawa 1997; Jha et al. 2000). Reptilian fauna is largely dominated by the Indo-Chinese element, relicts India's geological history. Approximately, out of 530 species of reptiles presently reported from India 197 comprises endemics, of these 98 endemics out of 260 species are reported from the Western Ghats (Daniel 2002). In spite of this high endemism, herpetofauna in India has received poor attention and has not been studied in detail (Vasudevan et al. 2001) and it is possible that a few of them have already been lost even before being reported (Dar et al. 2008). Pit vipers belong to the family Viperidae and subfamily Crotalinae, which is represented by 21 genera. Nineteen species of pit vipers have been reported from India (Bhide 2001) including seven from the Western Ghats (Kumar et al. 1998). All these species barring *Trimerusurus gramineus* are endemic to Western Ghats (Whitaker 1969; Whitaker & Captain 2004; Khaire 2006). Information on the distribution, abundance and present conservation status of pit vipers in Western Ghats is scanty.

MATERIALS AND METHODS

The present study was conducted in Mhadei Wildlife Sanctuary (MWS: 208.48km^2), Bhagwan Mahaveer Wildlife Sanctuary and National Park (BMWS & NP: 241km^2), Bondla Wildlife Sanctuary (BWS: 8km^2), Netravali Wildlife Sanctuary (NWS: 211.05km^2), Cotigao Wildlife Sanctuary (CWS: 86km^2) and in cashew *Anacardium occidentale* plantations within and adjoining areas of these protected areas (PA) (Fig. 1). Altitude of the study areas ranged from 20 to 800 m and consists of west coast tropical evergreen, cane brakes, wet bamboo brakes, west coast semi-evergreen, moist bamboo brakes, lateritic semi-evergreen forest, slightly moist teak forest, southern moist deciduous forest, southern secondary moist mixed deciduous forest, south Indian subtropical hill savannah woodland and southern subtropical hill forest (Champion & Seth 1968; Table 1). The ambient temperature usually fluctuates between 15 and 30 °C.

The distribution and abundance of pit vipers was studied in all the PAs mentioned above using band transect following Dahanukar & Padhey (2005). Surveys were carried out on foot in different seasons (summer - March to May, monsoon - June to October and winter - November to February) during June 2005 to January 2009. Surveys were conducted during both day and night in predetermined paths or roads (2500x20 m). Geographical position of each study area and location of each observation of the snake was recorded using a hand-held geographical positioning system (GPS). Relative humidity and ambient temperatures of the observation sites were recorded using a hygrometer and mercury thermometer respectively.

Transects were traversed everyday for a week at each site by the researcher with the help of local volunteers. The transects were repeated five times per season. Visual inspection of shrubs, trees, ground and leaf litter was carried out for locating the snakes. All pit vipers encountered during the surveys were identified up to species level following Smith (1943), Murthy (1990) and Daniel (2002). The individuals were not marked, the snakes sighted on any single transect on successive days were identified based on the scale count and was not included to calculate the abundance. Abundance (number of individuals sighted in each study area) is represented as mean ± standard error. The mean abundance of the three species in each of the study sites and across seasons (summer, monsoon and winter) was tested to know whether the seasonal variation in each study site has any influence in abundance of the species, using two-way ANOVA.

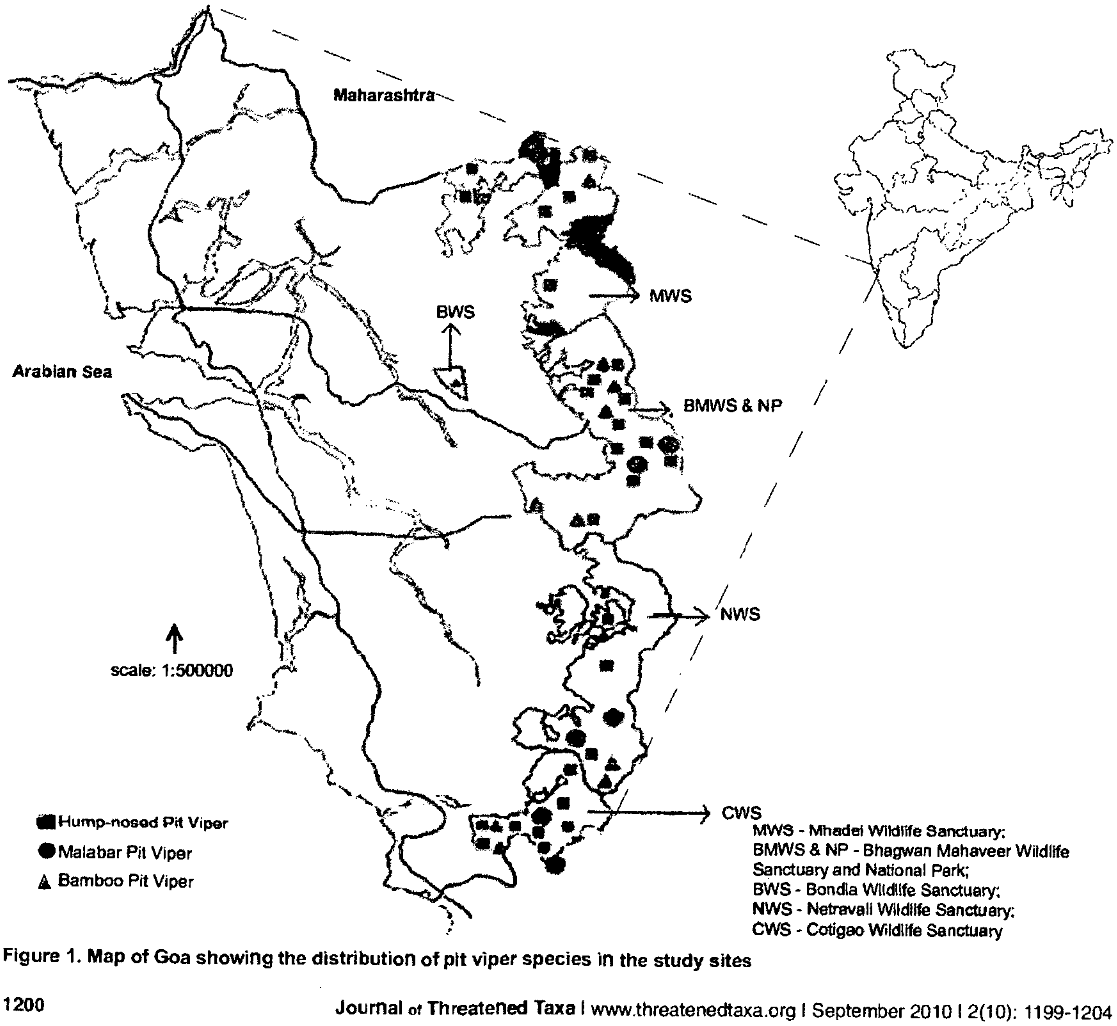

Figure 1. Map of Goa showing the distribution of pit viper species in the study sites

Table 1. List of forest types present in the study areas.

Forest type	Protected Area				
	MWS	BWS	BMWS & NP	NWS	CWS
West coast tropical evergreen	√		√	√	
Cane brakes	√	√	√	√	√
Wet bamboo brakes	√	√	√	√	√
Slightly moist teak forest	√		√	√	
Southern moist deciduous forests		√	√	√	√
South Indian subtropical savannah woodland	√		√	√	√
Southern subtropical hill forest			√	√	√
Southern secondary moist mixed forest	√	√		√	√
West coast semievergreen	√	√	√	√	√
Moist bamboo brakes	√	√	√		
Lateritic semievergreen forest	√	√	√		

RESULTS

In all, 45 transects (CWS - 7, MWS - 12, NWS - 7, BWS - 4 and BMWS & NP - 15) were sampled to assess the species distribution and abundance of pit vipers. Three species of pit vipers, *T. gramineus, T. malabaricus and H. hypnale* were recorded during this study (Images 1, 2, 3). A total of 356 pit vipers were observed during this study. *H. hypnale* was the most abundant species contributing (46.63%, n = 166) followed by *T. gramineus* (28.09 %, n = 100) and *T. malabaricus* (25.28%, n = 90). The abundance of pit vipers varied in different study locations (Table 3).

Image 1. Hump-nosed Pit Viper *Hypnale hypnale*

All three species of pit vipers were observed in all the study locations, except the BWS, where only *T. gramineus* was found. However, the locals report the presence of *T. malabaricus* in BWS. The forests type preferred by each species of pit vipers is listed in (Table 2). The temperature and humidity of the area during the present study ranged from 20.88 ± 5.25 °C to 32.44 ± 0.88 °C and 53 ± 4% to 93 ± 2% respectively.

T. malabaricus was observed at an altitude above 200m and exhibited occurrence at higher elevation in all the sites except in CWS; where it was recorded below 200m thus occupying the range between 123 and 765 m. *Trimeresurus gramineus* and *H. hypnale* were found from 37 to 672 m and 35 to 672 m respectively (Fig. 2). *T. malabaricus* and *T. gramineus* were observed at (mean & SD) 1.53 ± 1.6 m and 1.45 ± 0.68 m above ground respectively, whereas, *H. hypnale* was mostly found on the ground (beneath leaf litter), but, occasionally found on shrubs and herbs (up to 0.39m) as well.

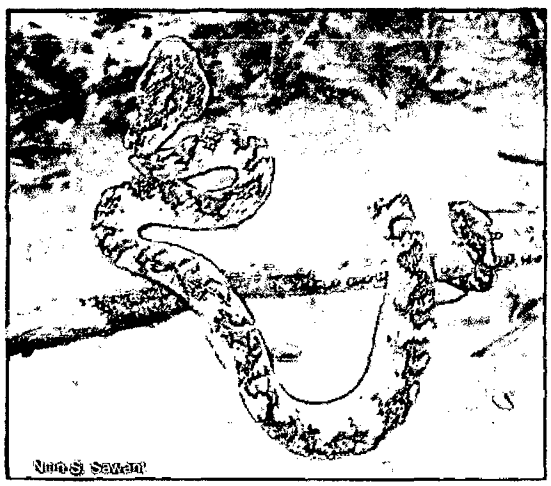

Image 2. Malabar Pit Viper *Trimeresurus malabaricus*

Distribution of pit vipers varied among seasons. During monsoon they were found in all 45 transects, whereas, in summer and winter they were observed in 35 transects which include transects having water bodies in the vicinity and transects in the cashew plantations, and were

Image 3. Bamboo Pit Viper *Trimeresurus gramineus*

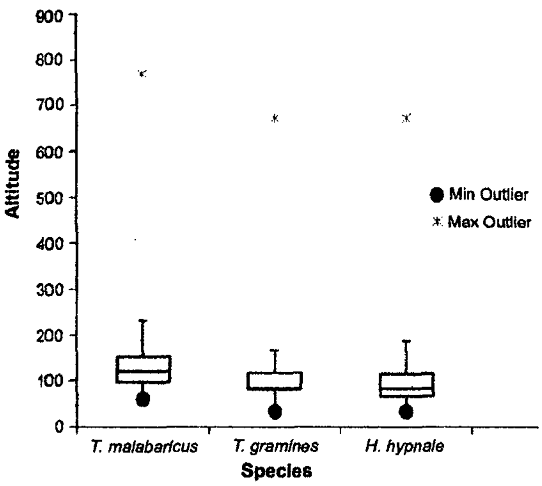

Figure 2. Graph showing mean ± SD, min and max value of altitude (in m) at which the pit viper species were observed in Goa

restricted to patches near moist areas. *H. hypnale* moved to adjoining cashew plantations during post monsoons (September and October) and winter, their abundance was high during monsoon in all transects (Table 4). ANOVA showed that the abundance of pit vipers varied significantly with seasons [*T. malabaricus* ($F = 3.20$, $p = 0.00058$), *T. gramineus* ($F = 3.20$, $p = 0.00028$) and *H. hypnale* ($F = 3.20$, $p = 0.015$)]. However, the abundance did not change significantly during each season when compared between sites.

DISCUSSION

Species in a reptile assemblage are not randomly distributed in space either horizontally or vertically, but occupy discrete microhabitat (Heatwole 1982). The distribution and abundance of all three species of pit vipers varied as their habitat-use was different. The *T. malabaricus* and *T. gramineus* are arboreal, whereas, *H. hypnale* is terrestrial in nature, however, a semi- arboreal behavior was also observed in *H. hypnale*. The present results augment the report of Murthy (1990). It was observed that most of the pit vipers were encountered in the regions having cool climate (segments of the transects with lower temperature and higher humidity) suggesting that the species prefer cool and moist places. Daltry et al. (1998) reported that the pit vipers typically remain motionless in areas with dense cover of undergrowth, suggesting this species is hygrophilic in nature. The three species remain highly camouflaged in their habitat and move very rarely exhibiting ambush behaviour.

Trimeresurus malabaricus predominantly occupied tropical semievergreen forests and rarely used moist deciduous forests. *Trimeresurus gramineus* and *H. hypnale* were observed largely in cane brakes, wet bamboo brakes, tropical semievergreen and moist

Table 2. List of forest types preferred by the pit vipers

Forest types	Pit viper species		
	T. malabaricus	*T. gramineus*	*H. hypnale*
West coast tropical evergreen	•	•	•
Cane brakes		•	•
Wet bamboo brakes		•	•
Slightly moist teak forest	•	•	•
Southern moist deciduous forests	•	•	
South Indian subtropical savannah woodland	•	•	•
Southern subtropical hill forest	•	•	•
Southern secondary moist mixed forest	•	•	•
West coast semievergreen	•	•	•
Moist bamboo brakes	•	•	•
Lateritic semievergreen forest	•	•	•

deciduous type of forest (Table 2). It was seen that all the three species were distributed in all study locations, barring BWS, where *T. malabaricus* and *H. hypnale* were not recorded during the present study. This could be due to the anthropogenic activities in and around the sanctuary as human disturbances can affect the snakes in terms of their distribution (Greene 1988; Peterson 1990; Brown 1993; Parent & Weatherhead 2000). Terrestrial and arboreal habitats differ profoundly in many ways including the types and amount of food availability, vulnerability to predators, and physical factors such as temperature and humidity. Those differences have resulted in many taxa becoming highly specialized. for either terrestrial or arboreal life and rarely venturing to alternative habitat (Plummer 1981; Luiselli et al. 2000; Vitt et al. 2000). *Trimeresurus malabaricus* and *T. gramineus* remain camouflaged in the thick canopy of the trees at an average height of 3-5 m from the ground, which could help avoiding avian predators. Sometimes they were also encountered while crossing the roads at night hours during the monsoon. This could be due to the thigmothermic response to warm surfaces, such as asphalt roads at night in nocturnal crotalines (Klauber 1972). This excursion to the ground could be driven by the availability of prey, especially frogs which are important food of pit vipers and mate searching, pheromonal trail following may result in males traveling further and longer to locate females (Shine et al. 2004). Further, *H. hypnale* was occasionally sighted among small herbs exhibiting semi-arboreal habit. The occasional use of arboreal habitat offers a good opportunity for the snake as it might reduce the efforts or energy needed to thermoregulate or search prey. Similar observations are reported by Oliveira & Martins (2001) and Shine et al. (2005). *H. hypnale* and *T. gramineus* preferred a broader range of altitude as compared to *T. malabaricus*, however *T. malabaricus* was also found at lower altitude in CWS suggesting that it is the ideal habitat with suitable hygrothermal profile and prey base which is the basic factor influencing distribution of these species. Some researchers (Campbell & Solorzano 1992; Huang et al. 2007) consider ambient temperatures to be the most important environmental factor limiting the altitudinal distribution of reptiles.

The remarkable change in the shift in habitat by *H. hypnale* was seen during the present study, wherein it was observed that during post monsoon and winter they occupy the cashew plantations (n = 45) adjoining the PAs. It is mainly due to the leaf litter, thick bushes which provides ideal microhabitat, suitable hygrothermal conditions, prey availability, and predator avoidance. Cool and humid environment below leaf litter provides good microclimatic condition for the forest floor reptiles (Kumar 2001), which is the major prey base for pit vipers. According to Block & Morrison (1998) leaf litter depth is an important factor in habitat selection in amphibians and reptiles. Since snakes are predatory in nature, therefore their local distribution might be influenced by distribution of prey abundance (Dar et al. 2008). It was seen that all the three species exhibited patchy distribution during summer and winter, confined to areas in close proximity of water bodies, whereas, in monsoons they were distributed in all transects.

Table 3. Observation of pit vipers in different study sites (Mean ± SE)

Study Area	Number of individuals of each species		
	T. malabaricus	*T. gramineus*	*H. hypnale*
CWS	7.75 (3.4)	7.25 (1.4)	9.5 (4.4)
BWS	0	2.75 (1.8)	0
MWS	8 (5)	5.25 (3.3)	9.75 (4.8)
BMWS & NP	3.5 (0.5)	3.75 (2.1)	14.5 (5.2)
NWS	3.25 (1.3)	4.75 (2.9)	7.75 (5.1)

Table 4. Variation in the observation of pit vipers among different seasons in the Western Ghats of Goa (Mean ± SE)

Species	Season		
	Summer	Monsoon	Winter
T. malabaricus	1.75 (1)	17 (6.9)	3.25 (1.7)
T. gramineus	2 (1.08)	18.5 (9.6)	3 (1.7)
H. hypnale	9.5 (2.1)	24.75 (14)	7.25 (4.3)

It was also seen that the abundance of all the three species varied in different seasons. The abundance was highest in monsoon compared to summer and winter. The highest abundance during monsoon was due to the suitable climatic conditions such as low temperature (22-24 °C), high humidity and rich prey base. In summer and winter the prey base (such as frogs) and suitable climatic conditions are restricted to patches in the vicinity of water bodies in the PAs. According to Sun et al. (2001) prey availability and abiotic factors, especially temperatures are the cues that drive seasonality in snakes.

It seems evident from the present study that pit vipers species are habitat specific and abiotic factors within the habitat such as seasonal changes in temperature and humidity, have influence on the distribution of these snakes. Hence, the protection of habitat is an important aspect in conservation of these species.

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Habitat suitability, threats and conservation strategies of Hump-nosed Pit Viper *Hypnale hypnale* Merrem (Reptilia: Viperidae) found in Western Ghats, Goa, India

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Abstract: Recent studies indicate that most species are best conserved in their natural community, which results in niche conservation. Depletion of any species is an irreversible change. In the present study the habitat ecology, threats and conservation strategies for the Hump-nosed Pit Viper *Hypnale hypnale* are suggested. The present study was undertaken in some protected areas (PAs) of Goa and the cashew plantations adjoining these PAs. *H. hypnale* prefers cool and moist places; most of the females of this species are found to spend the period from post monsoon to late summer in the cashew plantations adjoining and within the PAs, making them more susceptible to anthropogenic threats. We conclude that this pattern of seasonal changes in habitat use is mostly a consequence of niche conservation. However, this preference for a particular micro-habitat emphasizes the importance for the conservation of this snake population and although the most suitable habitat in the Western Ghats, for this species is included in the protected areas, specific guidelines are needed to assess conservation needs.

Keywords: Conservation, Goa, habitat, *Hypnale hypnale*, threats, Western Ghats.

INTRODUCTION

The habitat of a species can be defined as that portion of a multi-dimensional hyperspace (defined by any number of habitat factors) that is occupied by a given species (Whitaker et al. 1973). Data pertaining to interspecific niche partitioning by snakes has lagged behind that of other vertebrate groups, notably lizards and birds (Schoener 1977; Toft 1985). Descriptions of the preferred habitat is currently available for very few snake species (Reinert 1993) therefore, snakes are not well represented in studies of habitat selection. This is partly due to their secretive nature. They are difficult to locate and sightings are probably biased in favor of habitats where they are most visible. Measures of habitat suitability need to evaluate micro-habitat usage and animal movement patterns (Gumell et al. 2002). Studies on some snake species suggest that individual snakes do actively select a preferred portion of their environment (Reinert 1984; Weatherhead & Charland 1985; Burger & Zappalorti 1988; Weatherhead & Prior 1992) and the habitat selection is influenced by complex biotic and abiotic factors (Reinert 1993). Although some species are highly specialized and can exploit a narrow range of habitat, most taxa utilize a broader range, at least occasionally (Heatwole 1977). Thus, it is also important to understand why species shift among habitat type.

The State of Goa is located along the central west coast of India, lying between latitude 14°51'-15°48'N & 73°41'-74°20'E, with an area of 3702km^2. The forests of Goa have been classified into various types which include the west coast tropical evergreen, cane brakes, wet bamboo brakes, west coast semi-evergreen, moist bamboo brakes, lateritic semi-evergreen forest, slightly moist teak forest, southern moist deciduous forest, southern secondary moist mixed deciduous forest, south Indian sub-tropical hill savannah woodland, southern sub tropical hill forest, lateritic scrub and dry tropical river rain forest

(Champion & Seth 1968).

The Hump-nosed Pit Viper belongs to Family Viperidae and Subfamily Crotalinae. Three species of pit vipers are found in Goa viz. *Trimeresurus malabaricus, Trimeresurus gramineus* and *Hypnale hypnale* (Khaire 2006; Pradhan 2008; Sawant et al. 2010). Out of these three species *T. malabaricus* is endemic to the Western Ghats, *T. gramineus* is reported from Eastern and Western Ghats and *Hypnale hypnale* is found in the Western Ghats and Sri Lanka (Smith 1943; Whitaker 1978). Whereas *H. hypnale* has been recorded mainly from the southern part (up to about 16°N) of the Western Ghats and Sri Lanka (Smith 1943; Murthy 1990; Maduwage et al 2009), Maduwage et al. (2009) found no differences in specimens from the Western Ghats and from Sri Lanka.

The *H. hypnale* is both terrestrial and semi-arboreal in habit (Murthy 1990). The protected areas in Goa cover most of the Western Ghats region. The Goa region occupies about 2% of the total area of the Western Ghats (Joshi & Janarthanam 2004). The forests of the Western Ghats are very rich in wildlife and endemic species (Gadgil & Guha 1992). Many reptiles in the Western Ghats have restricted distribution, which is a major reason for many of them (63 Species) being threatened (Kumar et al. 1998). Despite high endemism and threat, there are only a few studies on the habitat preferences and community structure of reptiles in the Western Ghats (Inger et al. 1987; Bhupathy & Kannan 1997). The Western Ghats of south India have experienced large scale changes over the last century because of expansion and urbanisation (Nair 1991). Many of the world's species are threatened due to habitat destruction and fragmentation, which is the major cause of species endangerment (Dodd 1987; Mittermeier et al.1992; Wilson 1992; Losos et al. 1995; Fahrig 1997). Understanding the components of a snake's spatial and habitat ecology, such as movement patterns and habitat selection are therefore important in identifying features necessary for the preservation of a species (Dodd 1987,

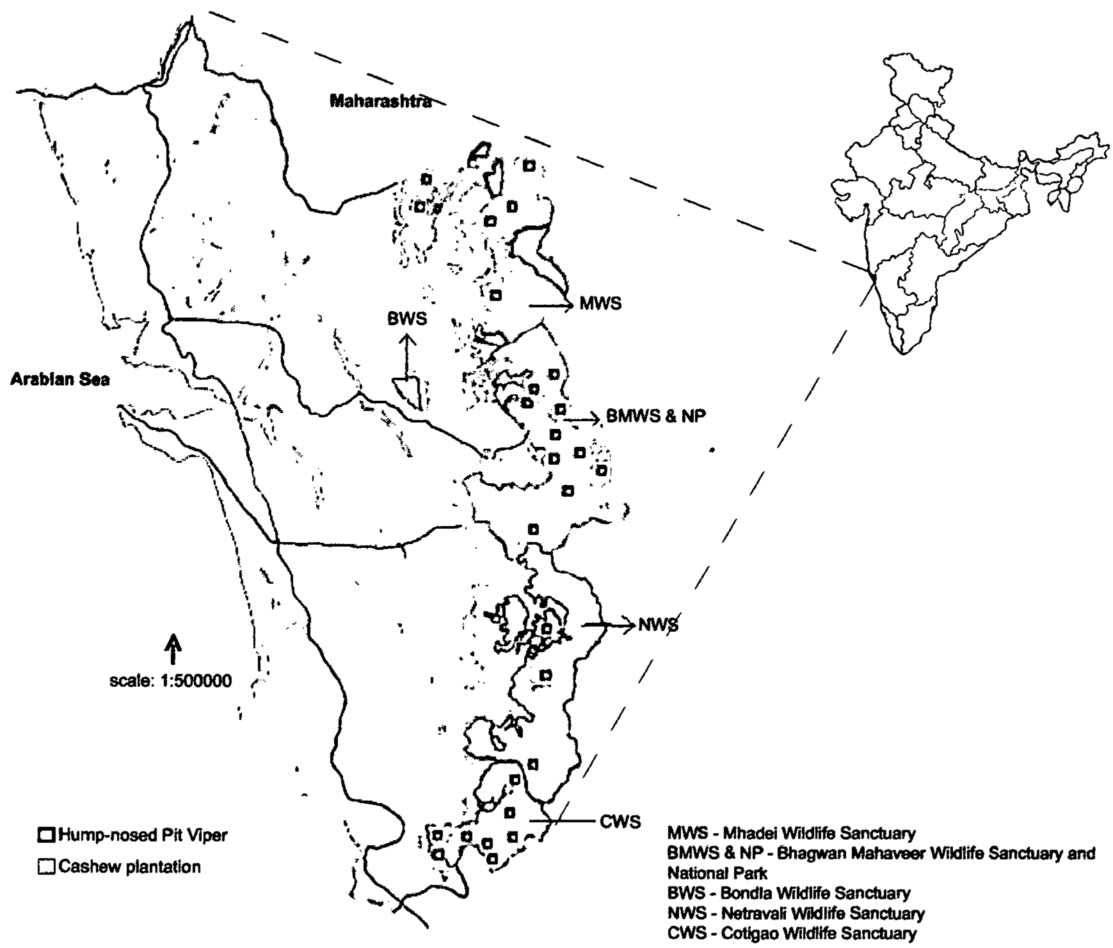

Figure 1. Distribution of *Hypnale hypnale* in the study sites and cashew plantations.

1993; Reinert 1993).

The habitat of *H. hypnale* in Goa (Western Ghats region) is vulnerable to several threats including climate change and anthropogenic threats, thus it is important to identify its macro and micro-habitat. Only limited information is available on the ecology of this snake and the studies of its spatial ecology have never been conducted. Thus, this study was undertaken to study the habitat of this species, seasonal variation in habitat use, to identify the threats and device strategies for the conservation of its habitat and population.

MATERIALS AND METHODS

The sites selected for the present study were the PAs in Goa which form a part of northern Western Ghats and run in a north-south direction (Fig. 1). The sites selected were Mhadei Wildlife Sanctuary (MWS), Bhagwan Mahaveer Wildlife Sanctuary and National Park (BMWS & NP), Bondla Wildlife Sanctuary (BWS), Netravali Wildlife Sanctuary (NWS), Cotigao Wildlife Sanctuary (CWS) and the cashew (*Anacardium occidentale*) plantations within and adjoining these PAs. The study sites lie at an average altitude of 20 to 800 m (from south to north).

Intensive surveys on foot were carried out in the Western Ghats region, from June 2005 to January 2009, in the five sanctuaries mentioned above. The possible habitat sites of *H. hypnale* were marked with band transects. An average path or road of 2.5km length was considered with a width of 20m (10m on both side of the transect). The distribution of *H. hypnale* was recorded using the transect sampling method as described in Dahanukar & Padhey (2005). Geographical positioning of the each location was obtained by hand-held Geographical Positioning System (GPS). Humidity and temperature were also recorded using a hygrometer and a mercury thermometer. In the cashew plantations the temperature and humidity of the leaf litter core was also recorded.

The transects were monitored regularly during day and night hours in different seasons and local inputs (secondary data) were also recorded. The survey involved an active search i.e. close visual inspection of shrubs, trees, ground, leaf litters. Secondary data included the collection of *H. hypnale* from local people (live & occasionally dead). During the survey the threats to this snake population and its habitat were also identified. The snakes were collected by snake sticks. All the snakes encountered during the survey were identified up to species level following the methodology of Smith (1943), Murthy (1989), and Daniel (2002). The number of snakes and their sex was recorded.

The data recorded from transects was used to estimate the species distribution in each study area. The data was also used to find the abundance of the species during different seasons. Variance among the abundance of the *H. hypnale* in study sites (forest area and cashew plantation) during different seasons (summer, monsoon, post monsoon and winter) was tested using the one-way ANOVA. Difference of $p < 0.05$ was regarded as statistically significant. All the calculations were carried out using the Microsoft Excel Software 2007.

RESULTS

In the present study, *H. hypnale* (Image 1) was found to occur in all of the study sites surveyed except in BWS (Fig. 1). Incidentally, locals have reported sighting of this species in precincts of BWS. The average temperature in all the study areas ranged from 20.88 ± 5.25 °C to 32.44 ± 0.88 °C. Whereas the humidity ranged from 53 ± 4 % to 93 ± 2 %. GPS records showed that *H. hypnale* was found at an altitude range of 35 to 627 m. It was observed that amongst the forest types present in the PAs of Goa, the *H. hypnale* preferred the west coast tropical evergreen, cane brakes, moist bamboo brakes, slightly moist teak forest, southern moist deciduous forests, south Indian sub-tropical savannah woodland, and southern sub-tropical hill type. During the present study, it was observed that the *H. hypnale* is an ambush predator and wiggles its tail to attract the prey, on some occasions it was encountered feeding on sinks, frogs and agamids. The predators of *H. hypnale* include predators such as the Crested Serpent-eagle, coucal, peacock and cobra which were sighted preying on *H. hypnale*; other potential predators include shikra, vipers, mongoose and civet cats. The same was also reported by locals. The list of floral and faunal associates of the *H. hypnale* is given in (Table 1). In most of the sightings the *H. hypnale* was found on the ground beneath the leaf litter. However, occasionally it was found on shrubs and herbs at an average height of up to 1.3 ft from the ground. It was also noted that during the post monsoons, winters and late summers the *H. hypnale* moved to the adjoining cashew plantations. The number of individuals sighted in the forest area and

Image 1. *Hypnale hypnale* in natural habitat

Table 1. List of floral and faunal associates of *H. hypnale*.

List of flora	List of fauna
Trees	**Mammals**
Tectona grandis	*Muntiacus muntjak*
Terminalia alata	*Viverricula indica*
Terminalia arjuna	*Paradoxurus hermaphroditus*
Terminalia tomentosa	*Axis axis*
Terminalia chebula	*Traguius meminna*
Terminalia crenulata	*Pteropus giganteus*
Terminalis paniculata	*Bos gaurus*
Terminalia bellirica	*Lepus nigrocollis*
Xylia xylocarpa	*Canis aureus*
Saraca asoca	*Macaca radiata*
Careya arborea	*Felis bengalensis*
Tabernaemontana heyneana	*Rusa unicolor*
Strychnos nux-vomica	*Hystrix indica*
Grewia tiliaefolia	**Reptiles**
Lagerstroemia speciosa	*Calotes versicolor*
Eupatorium odoratum	*Calotes rouxi*
Anacardium occidentale	*Naja naja*
Calycopteris floribunda	*Ophiophagus hannah*
Shrubs	*Cyrtodactylus dekkanensis*
Rauvolfia serpentina	*Hemidactylus brooki*
Leea indica	*Xenochrophis piscator*
Vitex negundo	*Macropisthodon plumbicolor*
Mussaenda glabra	*Bungarus caeruleus*
Herbs	*Draco dussumieri*
Eupatorium sp.	*Python molurus*
Gloriosa superba	*Varanus bengalensis*
Grasses	*Eutropis carinata*
Arundinella leptochloa	*Riopa punctata*
Bambusa arundinacea	*Trimeresurus gramineus*
Cynodon dactylon	*Vipera russelli*
Cyperus rotundus	*Echis carinatus*
	Trimeresurus malabaricus
	Aves
	Strix ocellata
	Pavo cristatus
	Accipiter badius
	Amphibians
	Hoplobatrachus tigerinus
	Hoplobatrachus crassus
	Indirana beddomii
	Fejervarya sp.
	Fejervarya keralensis
	Fejervarya rufescens
	Euphlyctis cyanophlyctis
	Sphaerotheca rolandae
	Sphaerotheca brevicaps
	Ramanella montana
	Sphaerotheca laucorhyncus

the cashew plantation during different seasons is given in Fig. 2. The Analysis of Variance (i.e. one-way ANOVA) for testing the abundance of *H. hypnale* for forest area with respect to different seasons showed that $p = 0.254$, $df = 3$, $F = 1.539$, whereas, the one-way ANOVA to test the abundance of *H. hypnale* for the cashew plantation with respect to different seasons showed that $p = 0.227$, $df = 3$, $F = 1.66$.

It was noted that the population which moved to the adjoining cashew plantations had low male: female ratio i.e. 0.227. It was also seen that most of the females that moved to the cashew plantations were gravid females. Thus, 65.9% of the total females sighted in the cashew plantations were gravid females. The temperature of the leaf litter core was 1.96 ± 1.32 °C lower than the ambient temperature, whereas the humidity was 5 ± 1.87 % higher than ambient humidity as compared to the forest area where the leaf litter temperature was 0.42 ± 0.13 °C lower and humidity was 1.8 ± 0.83 %, higher than the ambient temperature and humidity during the post monsoon and winter seasons. During the present study the following threats were identified.

(i) Habitat fragmentation due to encroachment and mining activities due to which most of the areas neighbouring the protected areas are affected.

(ii) The increasing population of peacocks might have put immense pressure on the population of the *H. hypnale* as it is one of the dominant predators found in all the study sites.

(iii) The major threat faced by the *H. hypnale* population is the anthropogenic pressure, especially due to their shift in habitat to the cashew plantations during the post monsoon and winter where they are killed out of fear by the labourers during the clearance of shrubs in the cashew plantations (Image 2).

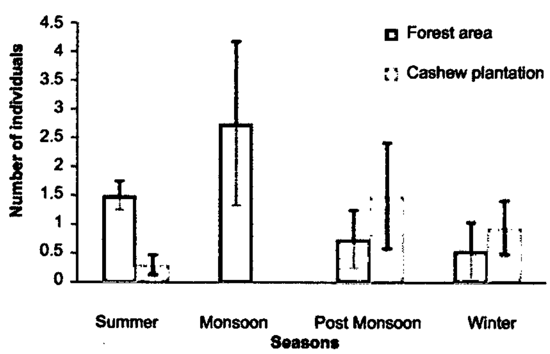

Figure 2. Average Number of individuals ± SE sighted in the forest area and cashew plantations during different seasons.

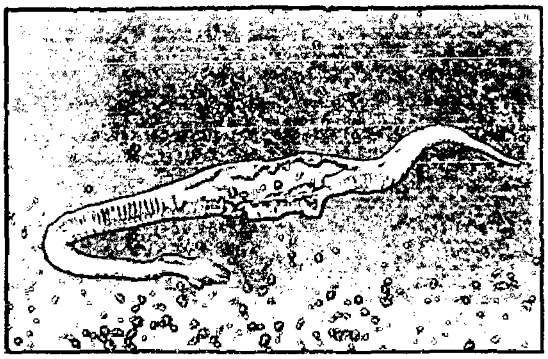

Image 2. Gravid female killed in cashew plantation during weed clearance

DISCUSSION

Habitat destruction is the major cause of endangerment for many of the world's threatened species (Losos et al. 1995; Fahrig 1997). It is therefore important to identify the habitats utilized by this species of pit viper and to protect the habitat relevant for their conservation. Identifying the habitat requirement, activity pattern and spatial distribution of a species is important towards the ecological management of this specie's population and habitats.

The present study revealed that the *H. hypnale* is in the Western Ghats (India) and distributed in parts of Maharashtra, Goa and southern parts of India. We observed that the *H. hypnale* preferred most of the forest type present in the protected areas of Goa. However, during the present study there was no record of the *H. hypnale* in the BWS. Incidentally, the locals reported the presence of *H. hypnale* in the vicinity of BWS. It is the smallest wildlife sanctuary of Goa and amongst the forest type preferred by the *H. hypnale*, only cane brakes, wet bamboo brakes, southern secondary moist mixed forest and west coast semi-evergreen, moist bamboo brakes and lateritic semi evergreen forest patches prevail in BWS. A possible factor which has affected this species may be the presence of a zoological garden in the sanctuary which attracts many tourists and a continuous flow of vehicles which causes disturbances of the habitat. Secondly this species shows a shift in habitat during different seasons, for which the hygrothermal profile such as cool and moist climate, leaf litter, suitable retreat and breeding site is not available at BWS throughout the year.

We observed that the *H. hypnale* occupied a broader altitudinal range (35 to 637 m) which suggests that factors such as temperature, humidity, basking sites and prey availability play a major role in habitat selection. These observations are in agreement with the report of Dial (1978), Huey et al. (1989), Madsen & Shine (1996), Kearney (2002), and Pringle et al. (2003). *Hypnale hypnale* is mostly terrestrial but has occasionally been encountered on herbs and shrubs; this excursion is obviously a part of the process of thermo-regulation. Shine et al. (2005) believed that climbing above ground level to facilitate thermo-regulation is widespread in snakes as in other ectotherms.

During the present study, it was observed that the *H. hypnale* showed a shift in habitat from natural confines within the protected areas into the cashew plantations. There are no previous records of such a shift in habitat shown by the *H. hypnale*. Interestingly, such a shift in habitat coincides with the breeding season and these interim movements are mostly exhibited by the females, especially by the gravid females. Males were very rarely encountered in the cashew plantations. The transient shift by the gravid females into the cashew monoculture merits discussion. The micro habitat requirement of the breeding individuals is perhaps best met in the cashew plantation owing to the density and thickness of the leaf litter. Reinert (1993) suggested that the need to locate essential resources such as food, shelter and gestation sites, influences habitat selection by snakes. A few studies (Houston & Shine 1994; Mullin & Cooper 2000; Shine & Sun 2002) showed that reptiles prefer habitat with a high prey abundance. Janzen & Schoener (1968) suggested that factors such as general reduction in the forest productivity in the dry seasons affect most animals including reptiles and their prey. Thus, less prey availability is the possible reason for the shift in habitat from the forest area to the cashew plantation. This also explains why there is a difference in sightings during different seasons. Henderson et al. (1979) reported that the effect of rainfall on snake activity may be indirect by affecting prey availability. The present study revealed that leaf litter core temperature was 1.96 $\pm$1.32°C lower than the ambient temperature, whereas the humidity was 5 $\pm$ 1.87 % higher than ambient humidity in the cashew plantation as compared to the forest area. This cool and humid climate below the leaf litter provides a good micro-climate for reptiles which is the major prey base for the reptiles. This in turn forms the prey base for the *H. hypnale*. This is supported by Kumar et al. (2001). Lima & Dill (1990) suggest that specific features of the leaf litter help reptiles to meet the conflicting demands of thermo-regulation, predator avoidance and participation in other activities.

Hypnale hypnale is a species of Western Ghats (India) and faces tremendous anthropogenic pressure. Habitat fragmentation due to mining activities around the protected areas is the immediate threat to this species. *H. hypnale* is a terrestrial species and ambush predator, which requires habitat such as a favourable hygrothermal profile, thick and moist leaf litter etc. The increase in avian predators such as the peacock has drastically reduced the population of this species and other reptiles and amphibians in some areas. During the post monsoon and winter periods, ground clearance in the cashew plantation is carried out to allow free movement under the plantation for cashew collection. During this process *H. hypnale* are encountered under small bushes and thick leaf litter. Thus this behavior of shifting habitat, especially by the gravid females to the cashew plantations is a cause of concern from the conservationist's point of view since the work force employed for such massive clearance, kills the snake out of fear. Such phenomenon is not uncommon in some parts of Goa, especially in places such as Sattari and Sanguem, and necessitates a conscious effort of educating the workers, on the conservation importance of these reptiles. Goa is a small state and mining is a major source of income for the state, most of the mining leases are around the protected areas, thus it has become very difficult to protect the habitat of this species. It is, therefore, important to create awareness among the communities to protect the habitat in order to protect these species. The government agencies (policy makers) play a vital role in directly conserving the habitat of the species, which in turn can aid in the indirect conservation of this species which is endemic in the Western Ghats and Sri Lanka.

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