Habitat Utilisation of Asian Water Monitor (*Varanus salvator*) in and Around Bhitarkanika National Park, Odisha

by

W. Michael Isaac V. Rayen
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Dissertation Thesis

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Under the supervision of

Dr. Abhijit Das, Scientist- E
Dr. Bivash Pandav, Scientist- G

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

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Wildlife Institute of India

DECLARATION

I hereby declare that the work conducted under the thesis entitled **"Habitat Utilisation of Asian Water Monitor (*Varanus salvator*) in and Around Bhitarkanika National Park, Odisha"**, is a record of original and independent research work done by me and subsequently submitted for the award of the degree of **Master's in Wildlife Science** at the **Academy of Scientific and Innovative Research**. This research work has been carried out under the guidance and supervision of **Dr. Abhijit Das, Scientist-E**, and co-supervision of **Dr. Bivash Pandav, Scientist-G** of Wildlife Institute of India, Dehradun. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my work, analysis, observation, understanding, and the particulars given in it are true to the best of my knowledge.

(W. Michael Isaac V. Rayen)
Enrolment No: 50BB23A73022
Place: Dehradun
Date: 24-06-2025

(Dr. Abhijit Das)
Supervisor

(Dr. Bivash Pandav)
Co-supervisor

पत्रपेटी सं. 18, चन्द्रबनी, देहरादून-248001, उत्तराखण्ड, भारत
Post Box No. 18, Chandrabani, Dehradun-248001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स. :+91-135-2640111 से 2640115, फैक्स :0135-2640117
EPABX : +91-135-2640111 to 2640115, Fax : 0135-2640117
ई–मेल/E-mail : wii@wii.gov.in, वेब/website : www.wii.gov.in

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

CERTIFICATE

This is to certify that the thesis by **W. Michael Isaac V. Rayen** entitled "**Habitat Utilisation of Asian Water Monitor (*Varanus salvator*) in and Around Bhitarkanika National Park, Odisha**" is an original and independent research work submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master's in Wildlife Science**.

W. Michael Isaac V. Rayen has conducted one semester of research, which is embodied in this thesis, under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma, or distinction.

(Dr. Abhijit Das)
Supervisor

Dr. Ruchi Badola
Dean
Faculty of Wildlife Science

पत्रपेटी सं. 18, चन्द्रबनी, देहरादून-248 001, उत्तराखण्ड, भारत
Post Box No. 18, Chandrabani, Dehradun - 248 001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स : +91-135-2640100, 2640114, 2640115, फैक्स : 0135-2640117
EPABX : +91-135-2640100, 2640114, 2640115, फैक्स : 0135-2640117
ई-मेल/E-mail : wii@wii.gov.in, वेब/Website : www.wii.gov.in

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Wildlife Institute of India

CERTIFICATE OF PLAGIARISM CHECK

It is certified that the M.Sc. Dissertation titled "**Habitat Utilisation of Asian Water Monitor (*Varanus Salvator*) in and Around Bhitarkanika National Park, Odisha**" submitted by **W. Michael Isaac V. Rayen** has been examined by us for plagiarism check as per UGC (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulations. The following inferences are drawn from this check:

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पत्रपेटी सं० 18, चन्द्रबनी, देहरादून – 248 001, उत्तराखण्ड, भारत
Post Box No. 18, Chandrabani, Dehradun - 248 001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स : +91-135-2640111 से 2640115 फैक्स : 0135-2640117
EPABX : +91-135-2640111 to 2640115 Fax : 0135-2640117
ई–मेल/E-mail : wii@wii.gov.in वेब/Website : www.wii.gov.in

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SUMMARY

The water monitor lizard *Varanus salvator* is the largest of all lizards in India, and its distribution is restricted to certain pockets of the northeast, eastern coast and Andaman and Nicobar Islands. Despite being the largest lizard, only limited studies have been done on this species, especially on the movement pattern and home range. This study focuses on the space use pattern of *Varanus salvator* in the mangrove habitats of Bhitarkanika National Park, Odisha. In total, five individuals were radio-tagged with VHF transmitters in the form of a backpack. All the tagged individuals were located twice in a day, and the location(coordinates), activity and other habitat variables were recorded. The data collected were analysed for their movement pattern, activity range and overlap between individuals and the human-dominated landscape was estimated using KDE. Along with the space use environmental variables (Ambient temperature, Relative humidity, vegetation species, canopy openness, etc) were analysed individually with behaviour to the relation between them using Fisher's test. The results from this study add more information about its activity range, movement pattern and behavioural aspects in the mangrove landscape of India, which can be useful in the rescue, rehabilitation and management of the species.

CONTENTS

INTRODUCTION:

`Home range' is the universal term for the living space of an organism and is generally defined as the area over which an animal moves during its daily activities of feeding, breeding, and shelter-seeking (Burt, 1943). The size of home range differs between individuals of a species (Rose, 1982) and between species (Harris et al., 1990). The home range size and shape are decided by the quantity of resources available in the respective area (Gehring & Swihart, 2003; Saïd & Servanty, 2005**.** For most large varanid species, reliable information about space use is scant, resulting in general confusion about patterns of movement and spatial requirements (Auffenberg et al., 1991; Phillips, 1995; Thompson, Boer & Pianka, 1999). One generalist species that has been known to adapt well to human-disturbed habitats throughout its broad Southeast Asian range is the Water Monitor Lizard (WML) (*Varanus salvator)* (Traeholt 1997a, b, c; Shine et al. 1998a; Gaulke et al. 1999; Horn 1999; Auliya 2003; Gaulke and Horn 2004; Uyeda 2009; Stanner 2010). The Water Monitor (*Varanus salvator*) is the largest monitor lizard of India, and the second largest in the world, after the Komodo Dragon (*V. komodoensis*). It has the widest global distribution among all varanids (Traeholt 1994). The distribution of the species in the Indian subcontinent was described by Das (1994), Daniel (1983), and Koch et al. (2013). They are semi-aquatic reptiles and prefer aquatic habitats like marshlands and mangrove swamps (Vogel 1979; Gaulke and Horn 2004). The extremely broad diet of the species is associated with a spatially large foraging area, where solitary individuals roam actively searching for live prey or carcasses for large portions of the day (Fitzsimons & Thomas, 2016; Karunarathna et al., 2017; Traeholt, 1994). (Traeholt, 1997c) documented reduced activity spaces in seasons where turtle nesting and tourist visits resulted in increased food concentration compared to seasons where food supplementation did not occur. The presence of humans may result in sensitive species choosing suboptimal conditions to avoid encountering human activity (Gaulke 1991, Colescott and Gillingham 1998). Conversely, generalist species may be attracted to greater food availability in human-modified areas (Treves and Karanth 2003, Dar et al. 2009), and may exhibit a loss of avoidance or escape response in the presence of humans (Whittaker and Knight 1998, Smith et al. 2005). Auliya (2003) predicted that the concentration of monitors would be higher in areas of human settlements, due to the presence of food or possible association between humans and food in the form of leftovers or garbage.

Although listed as Least Concern by the International Union for Conservation of Nature (IUCN), WML is among the most heavily exploited reptiles in the world for the international leather markets with hundreds of thousands of skins being exported annually from Asian countries (Luxmoore and Groombridge 1990; Shine et al. 1996; Koch et al. 2013). The species is listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2017). Various works have already been done on different aspects of water monitor lizards, including their ecology, behaviour, territoriality, population estimation, etc., mostly in protected habitats. However, no such study has still developed to understand the population in rural settlements crowded with humans (Hasmi et al. 2013, Koch et al. 2013, Stanner 2004).

To estimate the area of habitat used by species of interest has been estimated by the telemetry advancements, which enable the scientific community to engage in studying them (Hearn et al., 2018; Sastrawan & Ciofi, 2002; Stark et al., 2017). Very high frequency (VHF) telemetry has been used to study various species of varanids (Auffenberg, 1981; Bennett, 2014; Ciofi et al., 2007), with few of them focusing on *V. salvator* (Gaulke et al., 1999; Traeholt, 1995, 1997). In this study, we estimated the activity ranges, movement patterns, and factors influencing the free-ranging water monitors in the Bhitarkanika National Park. These findings offer insights into the species' natural history and provide a better understanding of its movement in mangrove habitats.

Keywords: Home range, Telemetry, VHF device(Very High Frequency), *Varanus salvator*, Activity range

OVERVIEW ABOUT THE SPECIES:

Taxonomy

The Asian Water Monitor Lizard (WML), *Varanus salvator,* is one of the most widely distributed monitor species (Cota *et al*., 2009). In India, they are limited to its eastern part, i.e., part of West Bengal, Orissa, North East India, and the Andaman and Nicobar Islands (Das, 2002). Presently, there are 5 recognised subspecies of the *V. salvator* complex (Welton et al. 2014b): *V. s. bivittatus* (Kuhl), *V. s. andamanensis* Derani yagala, *V. s. macromaculatus* Deraniyagala, *V. s. ziegleri* Koch & Bohme (Ziegler's Water Monitor), and *V. cumingi samarensis* Koch, Gaulke & Böhme (Sumar Water Monitor).

Physical description

Varanus salvator is the second-largest lizard species (Cota et al. 2009). It possesses a large size; a long, flattened body; a long tail and neck; and an extremely long, bifurcated tongue (Koch et al. 2007, Pough et al. 2004). WMLs have well-developed eyelids, and most members of the species have recurved teeth. Its head is covered with small scales, its body is covered with small round or oval scales, and ventral scales are arranged in regular rows (Pough et al. 2004). It has light-coloured pineal organs located dorsally on the head (Koch et al. 2007). This monitor has well-developed limbs, and its digits are armed with strong claws. Identifying characteristics include distinctive transverse black or dark bands or rows of spots or ocelli dorsally located on individuals, small nuchal scales with light dots on the neck, and a dark brown to black head (Koch et al. 2007). Juveniles have spots across their bodies and light underbellies

(Karunarathna et al. 2008b). Previous studies have recorded individuals of the *V. salvator* subspecies complex reaching total lengths (TL) of anywhere between 0.5 mm to over 2 m and nearly 3 m (Conrad et al. 2012; Karunarathna et al. 2008a, b; Koch et al. 2007; Lim 1958).

Habitat

The Asian Water Monitor is perhaps the most widespread of all varanids and is found in Sri Lanka, northern India, Bangladesh, Burma, Vietnam, Hainan (China), and through Malaysia east to the Indonesian islands of Sulawesi and Wetar (Cota et al. 2009, De Lisle 1996). The varanid lizards in this study are mobile with home ranges that encompass many types of microhabitats (Green and King 1978, Shine 1986, Christian and Weavers 1994). The WML is diurnal and, as its name suggests, is the most aquatic of the monitors (Pianka et al. 2004)

The lizard species occurs from sea level to an altitude of 1800 m, though water monitors are typically located in the lowlands, most commonly below 600 m (Bennett et al. 2010, Gaulke 1991). The species complex is found in warm tropical climates (activity temperatures recorded in Sri Lanka varied between 29.9 °C and 30.4 ± 2.1 °C), often preferring thermally stable habitats to help maintain relatively constant body temperatures (*V. salvator* has a body temperature of 36–38 °C, slightly lower than terrestrial varanids) (Wickramanayake and Dryden 1993).

The species group is closely associated with wetlands both fresh and brackish waters, tidal mudflats, and dikes (Rashid 2004), as well as deltaic swamps, evergreen rain forests, littoral forests, dried flat wetlands, clearings, and even savanna-like locations near forest edges, and can cross vast seawater distances between island locations (De Lisle 2007, Erdelen 1991, Pianka et al. 2004). It is often found thriving near human-modified areas/settlements, as human presence does not seem to deter these monitors (Amarasinghe et al. 2009, Gaulke 1991). They have been reported as much more abundant in human-inhabited areas (2400 monitors/km2) vs uninhabited areas (4 monitors/km2) (Uyeda 2009). In some instances, monitors have appeared on average to be larger and more robust in some areas of incidental human supplementation (Auliya 2003). Water monitors are excellent swimmers/divers, and aquatic habits provide individuals with an extra means of safety (Pianka et al. 2004). These lizards are capable of swimming in salt water for vast distances (Rawlinson et al. 1990). In addition, they spend a fair amount of time on land and are also excellent climbers, with juveniles being more arboreal than mature adults (Pianka et al. 2004).

Reproduction

The breeding season of the WML, which occurs between March and October, particularly after the first heavy rains following the long dry period (Shine et al. 1996; Cota 2011). The species is capable of multiple reproductive events per year (Pianka et al. 2004), the timing of which may be influenced by rainfall and can produce from 5 to 25 eggs per clutch. Also, the average incubation period was reported as 214.9 ± 6.9 days (Rashid 2004). In Singapore, female monitors were gravid or engaged in reproductive activity for the wet season from October to March (Rashid 2004). Wild individuals within the *V. salvator* complex show regional variation not only in their peak breeding seasons but also in clutch sizes, signifying the importance of climate and habitat on the breeding success of the population (Gaulke 1989, Shine et al. 1996). There is a direct correlation between clutch size and female body length, with larger females capable of generating larger clutch sizes (Rashid 2004, Shine et al. 1998).

Diet

Though Water Monitors are classified by some as scavengers feeding mainly on animal carcasses (Kulabtong and Mahaprom 2014, Traeholt 1995b, Daniel 2002), studies have indicated that their extensive diets include direct predation on wide range of animals from aquatic invertebrates to birds and mammals and everything in between and sometimes know to prey upon domestic pigs, chickens, and dogs in their range (Arbuckle 2009, Bennett 1998, De

Lisle 2007, Gaulke 1991, Gaulke and Horn 2004, Rashid 2004, Shine et al. 1998) as well as crabs (Cota et al. 2009).

Daily & Seasonal activity

There are widely varying reports of WML home-range sizes: 1.4 - 31.7 ha based on radiotelemetry data from Tulai Island, Malaysia (Traeholt 1997a, c); 20 ha to 120 ha (De Lisle 1996); and up to >150 ha for an individual living in the Ujung Kulon Nature Reserve in West Java, Indonesia (Gaulke et al. 1999, Vogel 1979). Studies have indicated home-range sizes vary depending on habitat (highly productive habitats, such as mangrove swamps, require smaller activity areas) and age (younger individuals have much smaller home ranges), with home ranges of ten overlapping, suggesting a lack of territoriality (Pianka et al. 2004). There have also been observations of a primarily size-based dominance hierarchy among individuals who frequent areas with human-provided resources (Uyeda et al. 2015). As a result of the tropical climate experienced in the natural range of the WML, seasonal changes in activity patterns are less pronounced, though in mainland locations during winter (December through February), temperatures can fall to 10 °C, and daily activity patterns start later and end earlier in the day (Pianka et al. 2004). In Sri Lanka, changes in foraging behaviour between the wet and dry seasons have also been observed, with foraging consisting of primarily aquatic activities (brief excursions on the banks of waterways) during the dry, high-temperature season, and primarily terrestrial activities (entering water only to cross waterways) during the rainy season, when there is cooler, overcast weather (Jolley and Meek 2007).

Research Gap:

Although the Asian water monitor is widely distributed, its home range and movement patterns remain poorly understood concerning the Indian population, especially in specialised habitats such as mangroves. The existing knowledge on the species' habitat utilisation is limited to general observations and large-scale studies, which are not sufficient to provide the detailed information required for informed conservation. The **present study answers the activity range of five male monitor lizards in a span of two months (February 15 – April 15) and how their movement pattern, along with behaviour, is dependent on the influence of environmental factors**.

METHODOLOGY

Study area

The Bhitarkanika mangrove forest is the second-largest mangrove forest in India. Mangroves of Bramhani and Baitarani delta of Kendrapara district have been declared as Bhitarkanika Wildlife Sanctuary in April 1975, covering an area of 672 sq. km. The core area of the sanctuary was declared as Bhitarkanika National Park in September 1998, covering an area of 145 sq. km(Lakshman Nayak et al, 2009). On its eastern side, the sanctuary is bordered by the Bay of Bengal, and the other three sides are bounded by the River Dhamara to the north, the River Maipura to the south, and the River Brahmani to the west. The sanctuary is interspersed with numerous creeks, and the vegetation is primarily mangrove. Some parts of the park lie on the higher ground and therefore lack mangrove cover(B. Pandav 1993). The annual rainfall ranges from 920 to 3,000 mm(Gopi et al, 2007), and the temperature varies from a minimum of 10°-15° C in December-January to a maximum of 40°-45° C in May-June(Behera et al, 2021).

Bhitarkanika represents one of the richest and most diversified mangrove floras in the country. Fifty-eight species of mangroves have so far been recorded in India, of which 55 are found in Bhitarkanika (Bannerjee and Rao 1990; Gopi et al. 2007). Significant aspects of the fauna of Bhitarkanika mangroves include the presence of India's largest and oldest known heronry (Gopi et al. 2007) and the occurrence of the Saltwater crocodile *Crocodylus porosus,* Water Monitor Lizard *Varanus salvator*, King Cobra

Ophiophagus hannah, Fishing Cat *Prionailurus viverrinus*, Striped Hyaena, *Sambar Cervus unicolour,* among others.

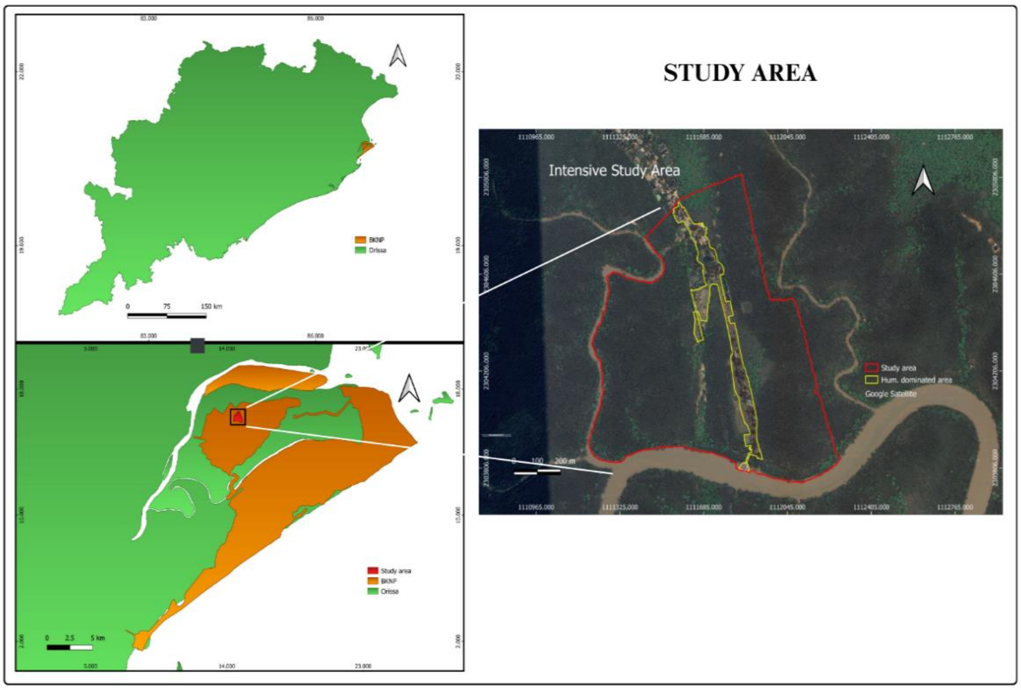


Fig. 1: Intensive study area (ISA)

This study was conducted on Dangamala block, which was considered my intensive study area(ISA), and the area spans 80.4 Ha. I've fixed my ISA based on the extent of the location points I got. Creeks with crocodile movement acted as a barrier for monitors on the west and southern side of the ISA, which prevented them from moving further. ISA has both dry and swampy mangrove habitats, with human human-dominated area of about 6.5 Ha. Aligning with the monitor activity pattern, there will be human presence from 6 AM-6:30 PM, most of the activity will overlap, but with the least interaction.

Field Methods

Animal capture: The study duration is from 1st of January to 15th of April, which is the transition phase from winter to summer. Capturing of WMLs started from 12th February, total five lizards ranging from 5- 8 Kg were captured through pipe and noose, once the captured individuals are secured, their head, body, tail and cloacal temperature along with weight, girth, sex(most of the time they evert their hemi-penies in the restraining process), SVL, head, tail and total length were also measured. Once, morphometric measurements were done, they were fitted with Holohil VHF transmitters(AI-2B & PD-2) on their back in the form of a backpack (Fig. 1). The whole weight of the transmitters and the Teflon tubes was less than 5% of the animal's weight. Each of the captured individuals' heads was photographed from both sides to identify them. All the captured lizards were released at the same location of capture and left. To get acclimatised for three consecutive days.

Fig. 2: VHF attached at the pelvic area of WML

Data collection: Tracking was done twice a day (6-9 am and 12- 3 pm) for day one and (9 am-12 pm and 3-6 pm) for the next day; this trend was repeated until the end of the study. This was to make sure that we cover the entire time frame of 6 am -6 pm, which was the activity period of this lizard. Lizards were tracked down to their habitat with a foldable antenna of Telonics (Model RA-23) and the Telonics TR-8 receiver. Once they got in the sight, with the least disturbance we got close as much as 2m (not less than that) to get the location data and vegetation patch(species), canopy cover, perching height(if arboreal), ambient temperature, substrate, relative humidity, pneumatophore density, tide, distance to the nearest vegetation and behaviour. If we felt the animal was disturbed due to our presence, either the tracking will be abandoned to prevent our influence on its movement or we'll look for the trails/marks from the direction peak of signal, and it will be marked as the animal location, without the habitat variables or behaviour being noted.

Behaviour: WML observed behaviours in the study period are explained below

- **Basking:** Animal stays still while exposed to direct sunlight, with dorsoventral touch the substrate; head and forebody raised off with limbs stretched straight or lying on the substrate.
- **Walking:** WML will be in alert mode, legs straight and head up with occasional movement to the side. The tongue sticks out of the mouth, sometimes quickly in and out of the mouth, drooling. The frequency of the tongue flicks is directly proportional to the state of alert or searching. The lizard can be stationary or walk back and forth at a point on the ground, looking for prey.
- **Resting:** WML stay in shady areas, not exposed to direct sunlight, mostly under high canopy cover, the position of the head and forebody is raised or lying on the ground with limbs outstretched. WML will take shelter to cool down their temperature.

- **Swiming:** WML is in alert mode, head up with movement to the side, body will be submerged under water. The tongue sticks out of the mouth, sometimes quickly in and out of the mouth. The lizard can be stationary or swimming, looking for prey.

Parameters: Length, girth and weight were measured with the measuring tape and a weighing scale, respectively. Body surface temperature (on head, trunk and tail) was measured with Extech RH401 Digital Psychrometer and IR Thermometer. For cloacal temperature, a mercury thermometer was inserted (10cm) into the cloaca for around 2 minutes. Ambient temperature and relative humidity were measured at 1m above ground level using Extech RH401 Digital Psychrometer and IR Thermometer, Pneumatophore density was measured in a scale of 0, 1, 2, 3, tide and canopy openness was measured through mobile applications(Tides and GLAMA respectively) and the GPS coordinates were noted in Garmin 32x.

At the end of the study, all the tagged individuals were captured again, and all the morphometric measurements were taken before removing the transmitters. Three of the five individuals in which we used the smaller tags had minor injuries due to Teflon tubes, and they were left to heal on their own.

Statistical analyses

All the statistical analyses were done using R Studio version 4.3.1. To calculate the activity range of individual WML, I used KDE using the package (adehabitatHR). Also, to visualise the trend between the area of activity ranges and weight class of WMLs, we performed linear regression modelling. All the WMLs had significant overlap; to calculate the area, we used the package (st_intersection()). To get the relation between vegetation species and substrate on the behaviour of WMLs, we did Fisher's Test. When the value is significant, we did a Chi-square test to get the standardised residuals. The results of standardised residuals are plotted in a heat map (both the environmental variables are analysed separately)

RESULT

Water monitor lizards were tracked for 50 days from the winter to the summer transition phase. All five individuals were males, and the study period didn't overlap with their mating season, which made it simpler. All the morphometric measurements and the number of data points (GPS coordinates) for each individual were mentioned in table 1. During late March, the transmitter of Dragon 4 stopped functioning and was lost. Later, the individual was caught, and the Teflon harness was removed.

Table 3: Showing the Morphometric measurements of captured WMLs

ID	SVL (cm)	Head length (cm)	Tail length (cm)	Total length (cm)	Weight (Kg)	Grith (cm)	No. of Data points
Dragon 1	66.5	11.5	96	161.5	7.76	50	46
Dragon 2	64.25	11.25	83.25	145.25	5.23	39	54
Dragon 3	69.25	12	100.5	168	7	46.25	68
Dragon 4	67	12	91.5	158.5	6.81	47.5	45
Dragon 5	69.5	12.75	85.2	152.05	5.40	39.5	70

Movement pattern

Total distance, WMLs travelled in the entire study based on the number of points for each WML, was calculated and mentioned in Table 2. The distance between each consecutive point for each dragon was calculated to estimate the distance moved (the distance travelled by each individual estimated here is not exactly true; these are the limitations of VHF transmitters; either GPS or satellite transmitters do a better job in estimating the distance moved by the animal). The total distance travelled by Dragon 3 is longer, and it started earlier because I've tagged the same WML with a colour band in its right axilla previously, when we got the permission.

Table 4: Net displacement of WMLs in the entire study

ID	Total displacement (Km)
Dragon 1	3.5
Dragon 2	2.7
Dragon 3	6.4
Dragon 4	4.3
Dragon 5	2.9

Fig. 3 shows the raw pathway of all five tagged individuals; the raw track is just for visual representation of their movement across the study area. Also, the overlap within themselves is seen in Fig. 3, the lines between each consecutive point were straight because it was the aerial distance.

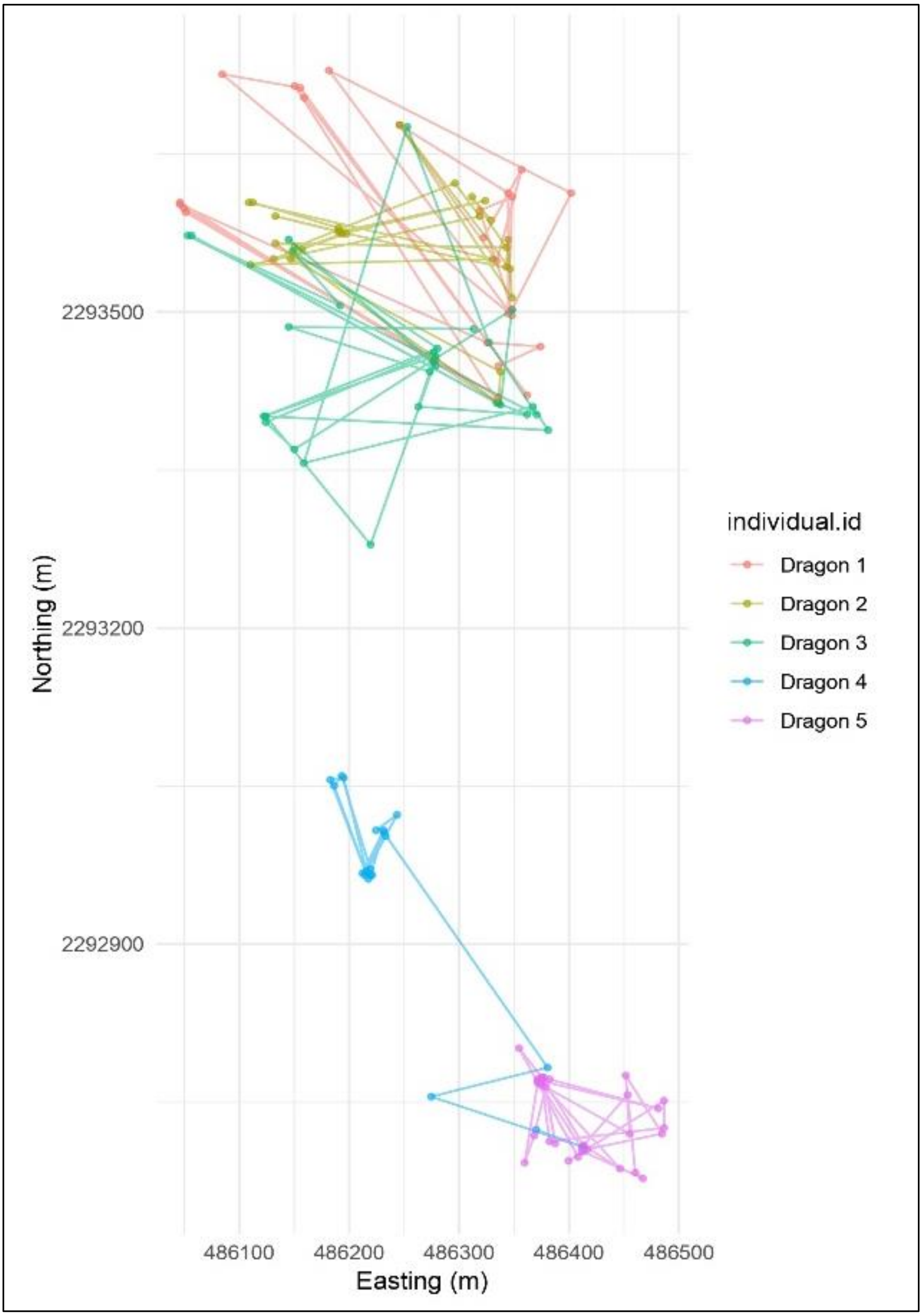


Fig. 3: Raw pathway for each WMLs

Moreover, each individual has site preferences within their activity ranges, for a specific activity, and the same site is used for multiple purposes. Fig. 4-8 explains the number of times a specific individual visited the same area and for what purpose (Frequency of visit).

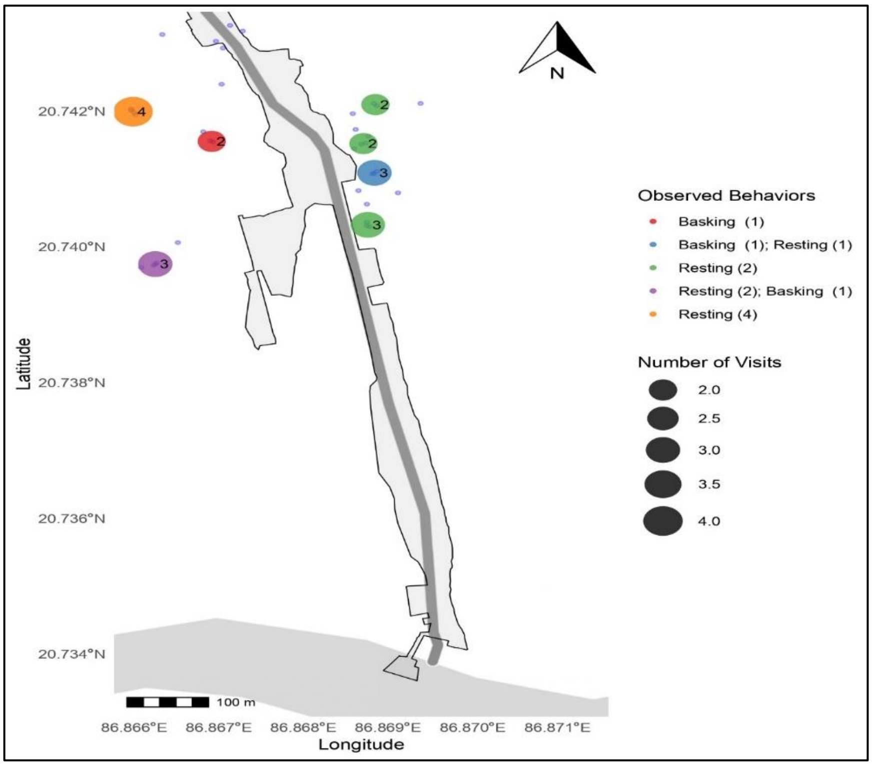


Fig. 4: Frequented points of Dragon 1

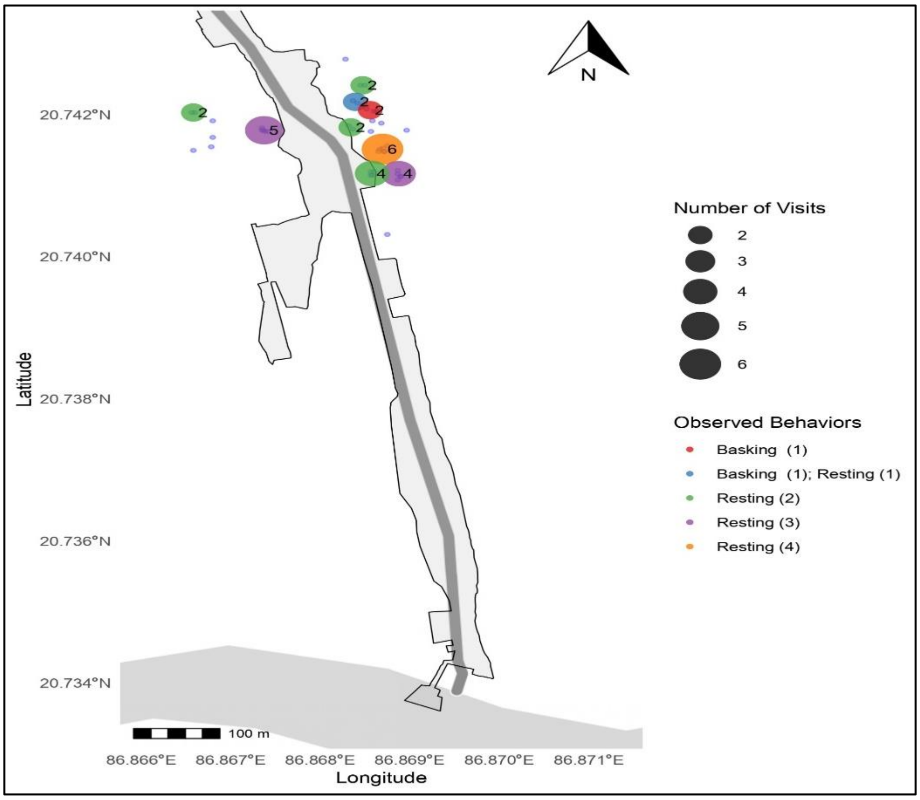


Fig. 5: Frequented points of Dragon 2

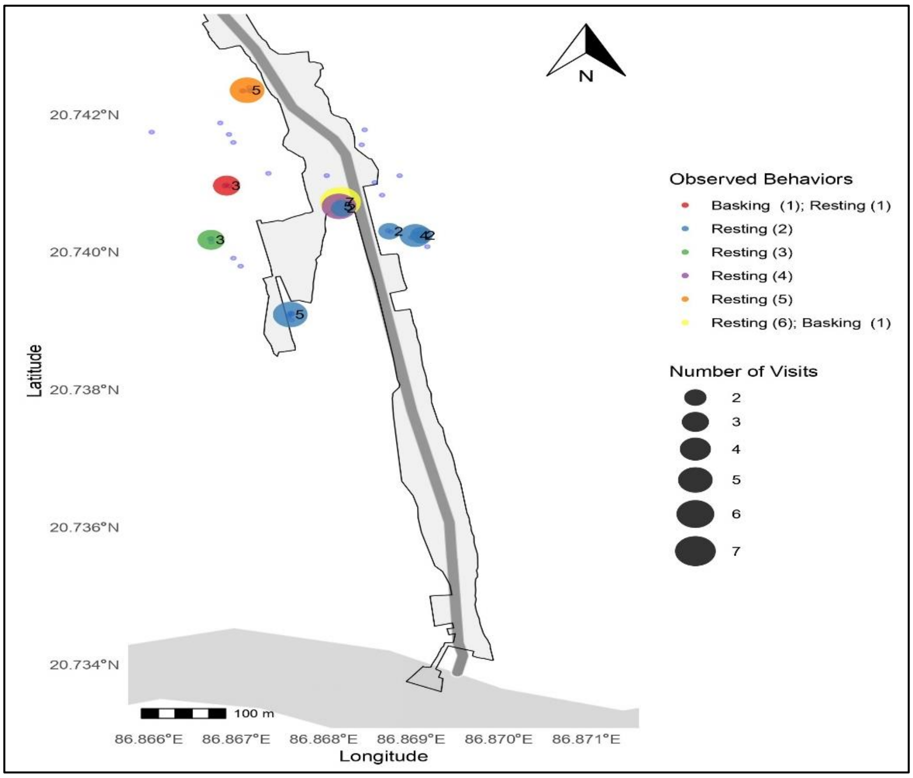


Fig. 6: Frequented points of Dragon 3

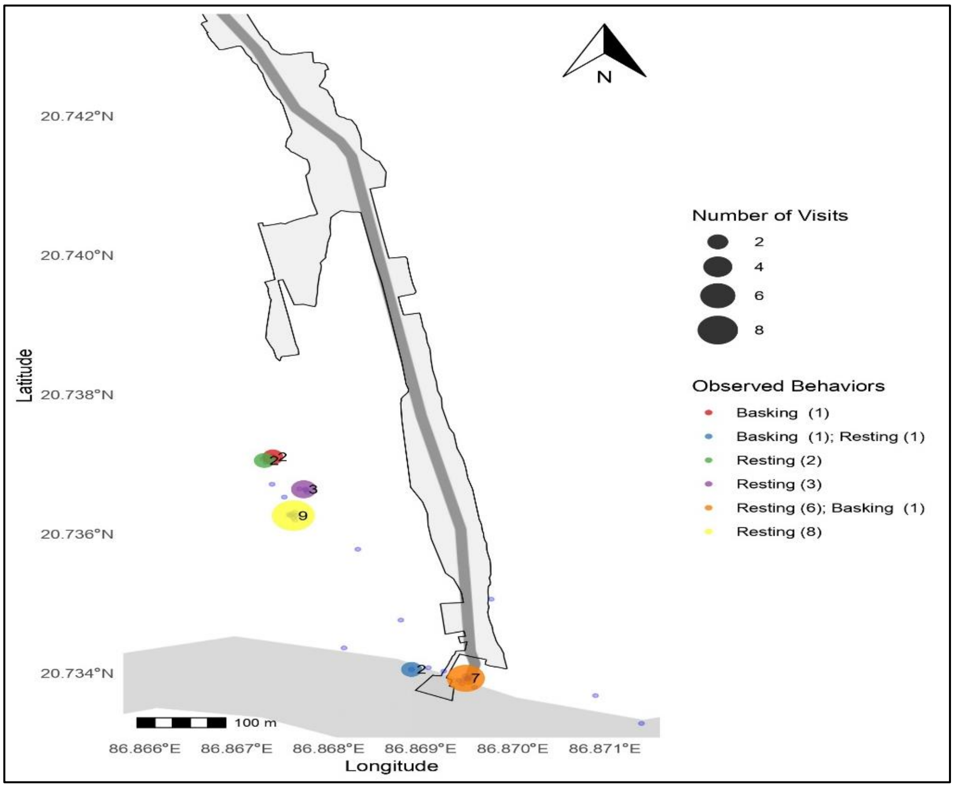


Fig. 7: Frequented points of Dragon 4

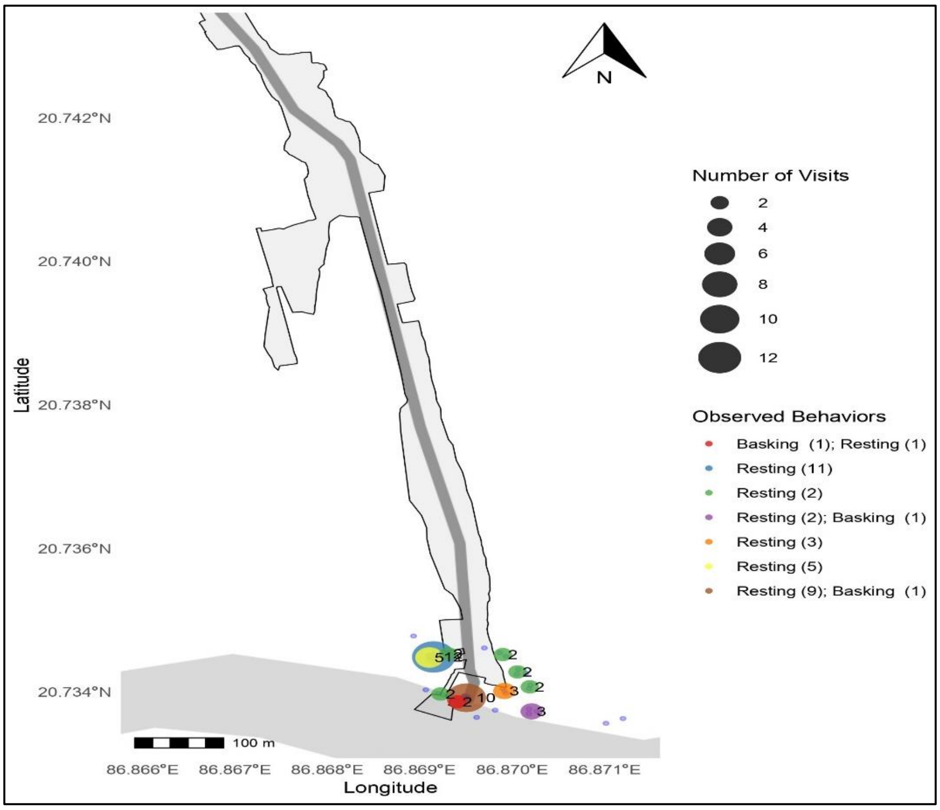


Fig. 8: Frequented points of Dragon 5

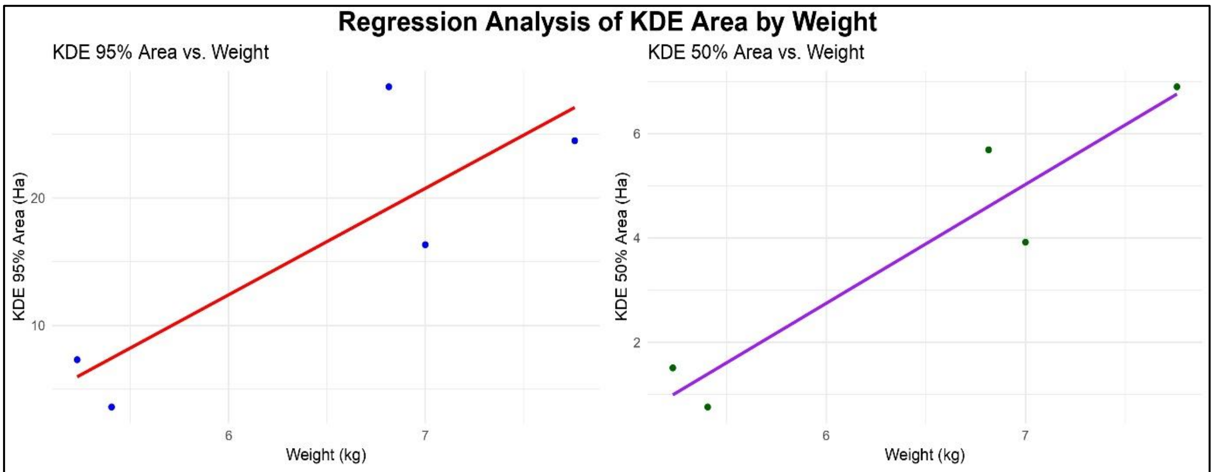
Activity range

The total activity range for all five monitors was individually estimated using kernel density estimate(KDE) with three different isopleths(95%, 50% and 25%). The 95% isopleth describes the maximum extent the animal can move based on the pre-existing points(including the outliers); it holds the largest home-range estimate. The 50% estimate calculates the actual area used by the animal by omitting the outliers and gives a more accurate estimate. When we conducted a 25% analysis to examine the core area, it estimated the area where the points clustered the most and provided us with results for each individual. In the broader literature on non-parametric density estimation, KDE is known to be statistically optimal (Silverman 1986).

Table 3: Showing the activity range of WML

Name	Initial weight (Kg)	Final weight (Kg)	SVL (cm)	KDE 95%(ha)	KDE 50%(ha)	KDE 25%(ha)
Dragon 1	7.76	7.14	66.5	24.49	6.90	2.23
Dragon 2	5.23	5.17	64.25	7.31	1.51	0.53
Dragon 3	7	7.02	69.25	16.33	3.92	1.32
Dragon 4	6.81	7.11	67	28.72	5.69	1.68
Dragon 5	5.40	5.68	69.5	3.60	0.76	0.25

Based on the Table 3 data, there is a relation between the area of activity range with respect to the weight class of the WML. A simple linear regression model was carried out to check for the significance of weight over the activity range size.



Regression Coefficients

Model	Term	Estimate	Std.Error	T Value	P Value
KDE 95% Area	(Intercept)	−37.6980	19.9668	−1.8880	0.1555
KDE 95% Area	Weight_kg	8.3496	3.0647	2.7244	0.0723
KDE 50% Area	(Intercept)	−10.9275	3.0387	−3.5961	0.0369
KDE 50% Area	Weight_kg	2.2793	0.4664	4.8869	0.0164

Model Fit Statistics

Model	R−squared	Adj. R−squared
KDE 95% Area	0.7122	0.6162
KDE 50% Area	0.8884	0.8512

Fig. 9: Regression analysis for activity range and weight of WML

Regression analysis explains the positive trend in activity range with the increase in weight of the WML for both 95% and 50% KDE. But the P value for 95% KDE(0.0723) is larger than the significance value of 0.05, which makes the relation not significant. On the other hand, the 50% KDE shows a significant value of 0.0164 in relation to the weight. The focus of this analysis is to check the influence of weight on the area of activity range, but due to insufficient data (5 activity ranges), it's hard to conclude whether the weight of WML has an impact on the activity range, even when the results are both significant and non-significant.

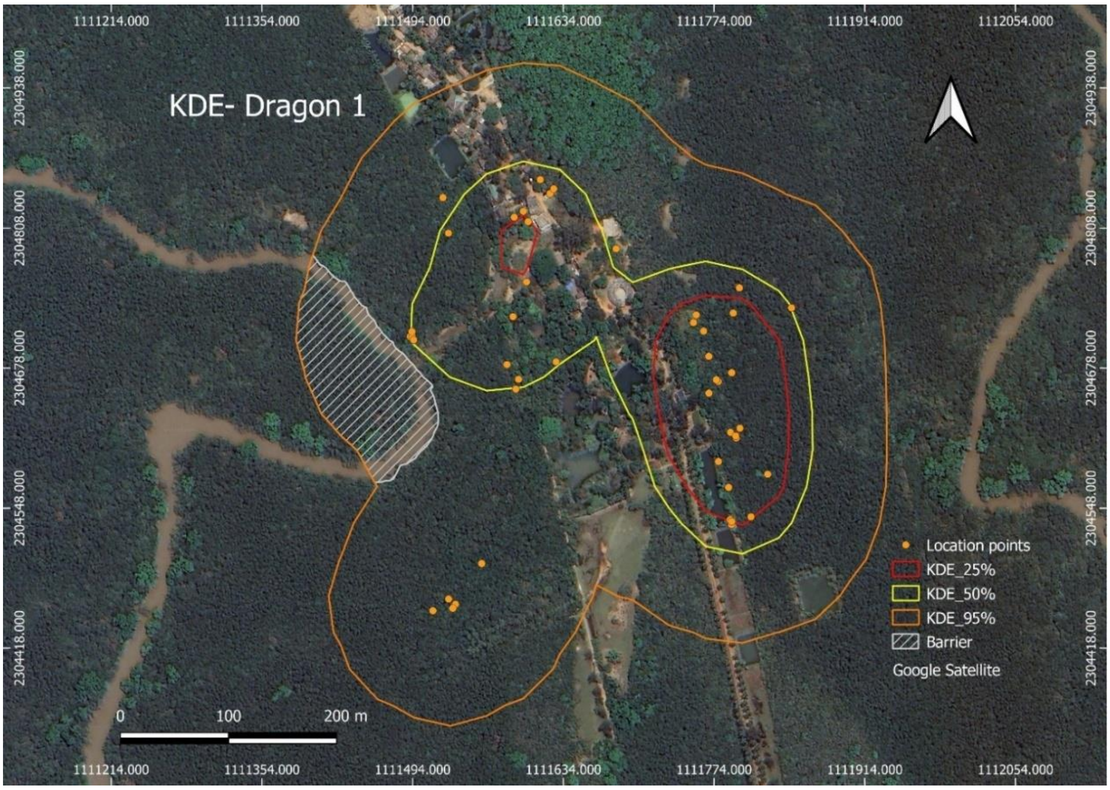


Fig. 10: Map showing the activity range of dragon 1

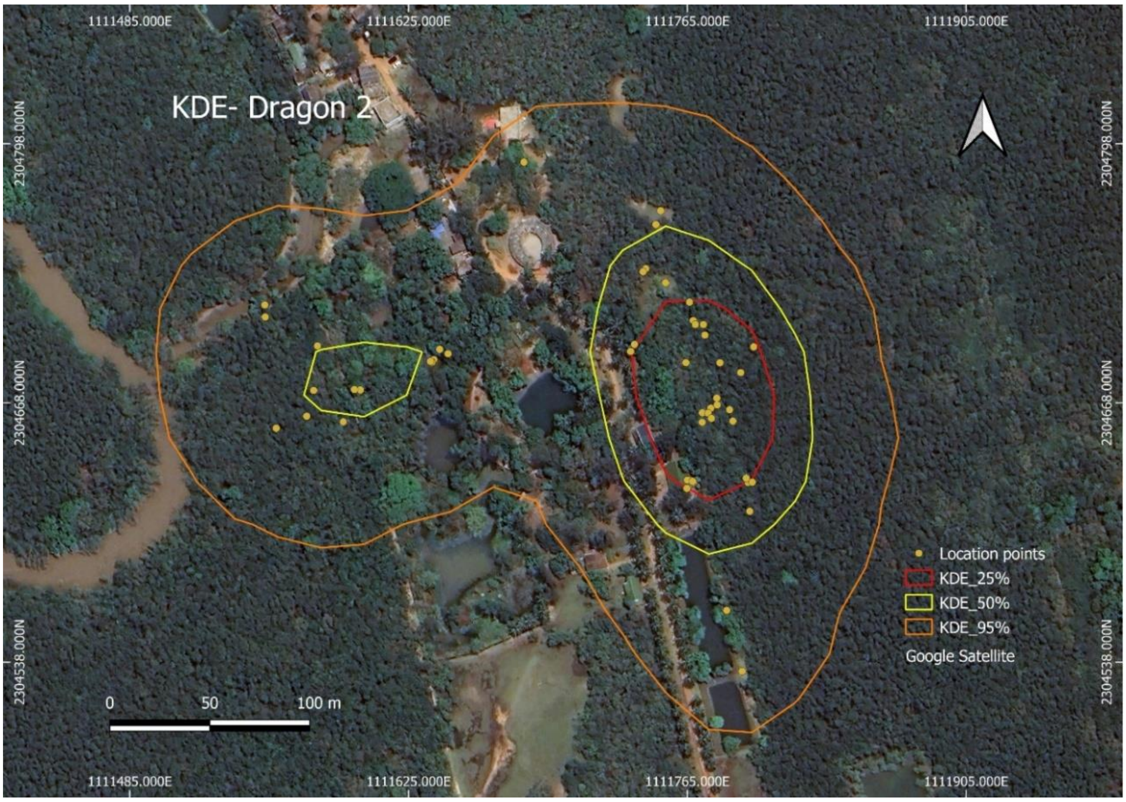


Fig. 11: Map showing the activity range of dragon 2

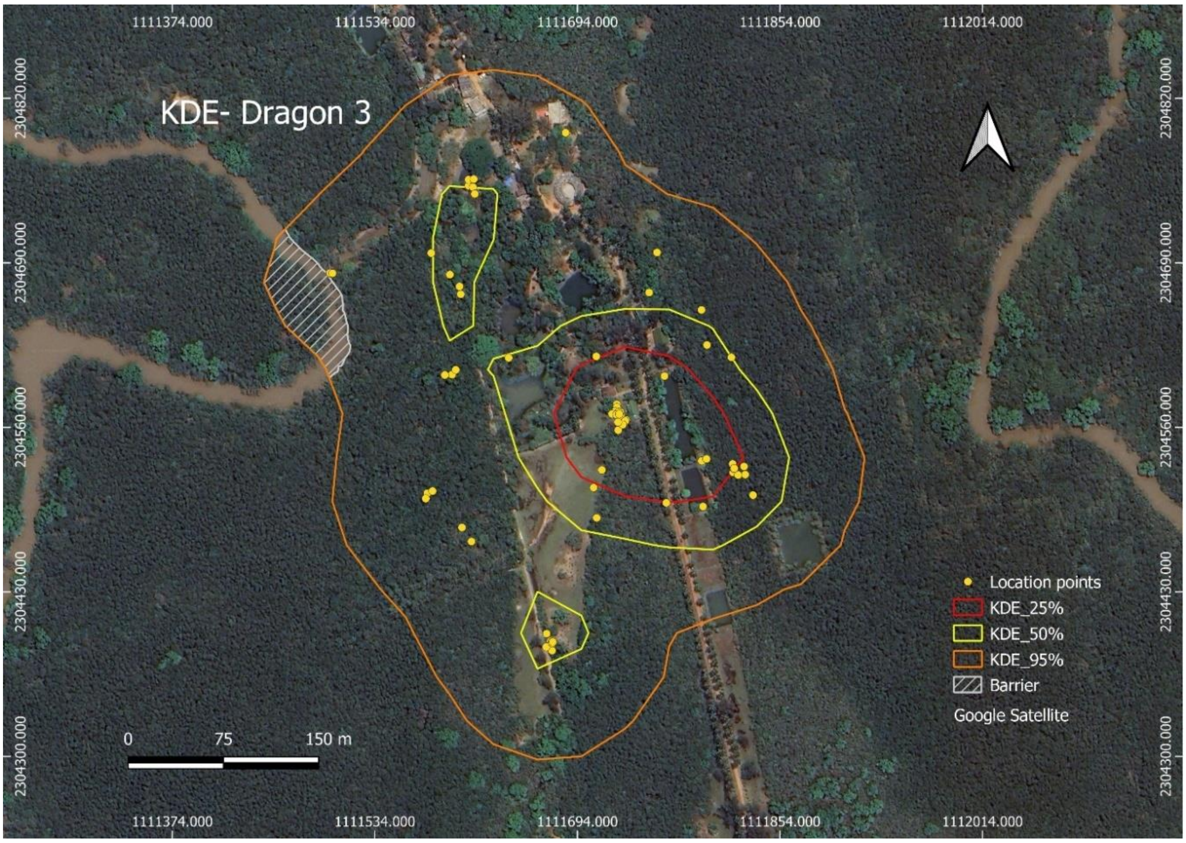


Fig. 12: Map showing the activity range of dragon 3

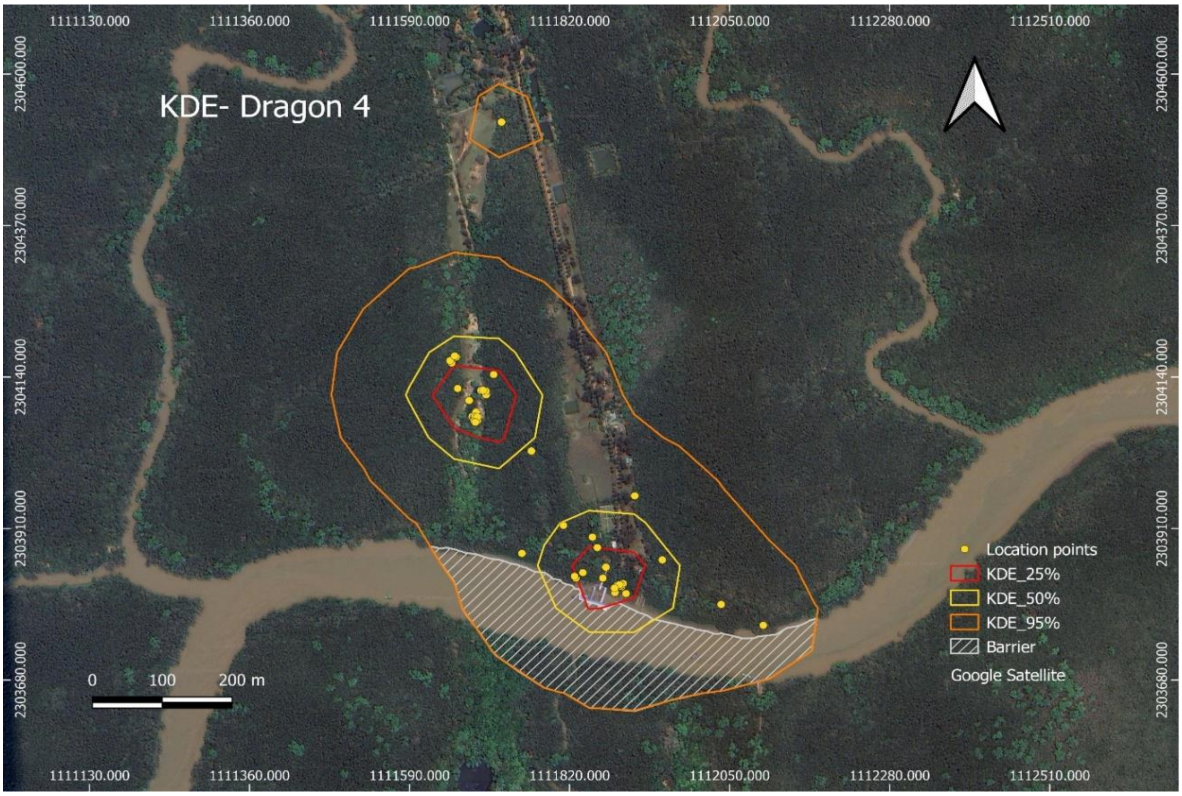


Fig. 13: Map showing the activity range of dragon 4

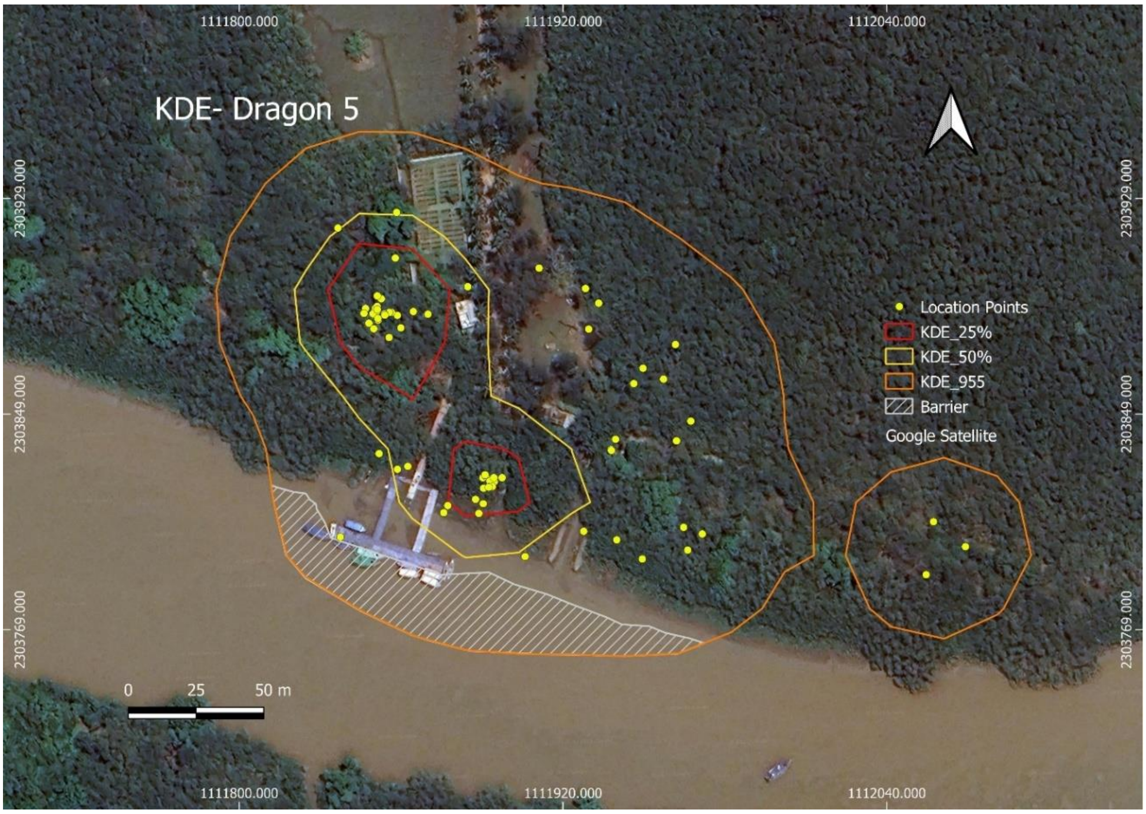


Fig.14: Map showing the activity range of dragon 5

When we see the KDE 95% for dragons 1, 3, 4 and 5, it has overlapped with the creek and the forest patch on the other side of the creek, which is impossible for the monitors to utilise. The places that can't be used by WMLs were marked as barriers on the map. After excluding barriers, the actual KDE 95% of WML activity range is shown in the table.

Table 4: Actual activity range, after omitting inaccessible areas

ID	KDE 95%(Ha)	KDE50%(Ha)	Barrier area (Ha)	Actual 95%(Ha)
Dragon 1	24.49	6.90	1.48	23.01
Dragon 2	7.31	1.51	0	7.31
Dragon 3	16.33	3.92	0.41	15.92
Dragon 4	28.72	5.69	6.19	22.53
Dragon 5	3.60	0.76	0.32	3.28

Overlap

I've estimated the overlap with the human-dominated area (6.5Ha), which is mentioned in Table 5.

Table 5: Range overlap with human-dominated area

Name	KDE 95%(Ha)	HD-Overlap 95% (Ha)	% of Overlap KDE-95%	KDE 50%(Ha)	HD-Overlap 50% (Ha)	% of Overlap KDE-50%
Dragon 1	24.49	3.19	13.85%	6.90	1.87	27.04%
Dragon 2	7.31	1.64	22.43%	1.51	0.27	17.67%
Dragon 3	16.33	3.4	21.33%	3.92	1.31	33.45%
Dragon 4	28.72	2.57	11.40%	5.69	0.52	9.17%
Dragon 5	3.60	0.56	17.14%	0.76	0.12	16.50%

Table 5 gives insight into the proportion of the area they use in human-dominated(HD) landscapes, with not more than 35% of the area in HD landscapes. Most of the points located inside the HD area were of foraging or resting, or investigative walk behaviour; none of the individuals were into basking behaviour, except for the individuals which are very near the vegetation patch. In case of resting the animals, they are either in burrows or septic tanks, through which they avoid direct interaction with humans.

Total spatial overlap of activity range within WMLs were also estimated for both 95% and 50% KDE. The highest of the overlap is with dragon 1 and 3 in both 95% and 50% KDE. Dragon 4 overlapped(KDE 95%) with dragon 1, 2 and 3 because of one outlying point where it came to feed on the dead chital, except for that incident the dragon 4 never came to the northern part of ISA.

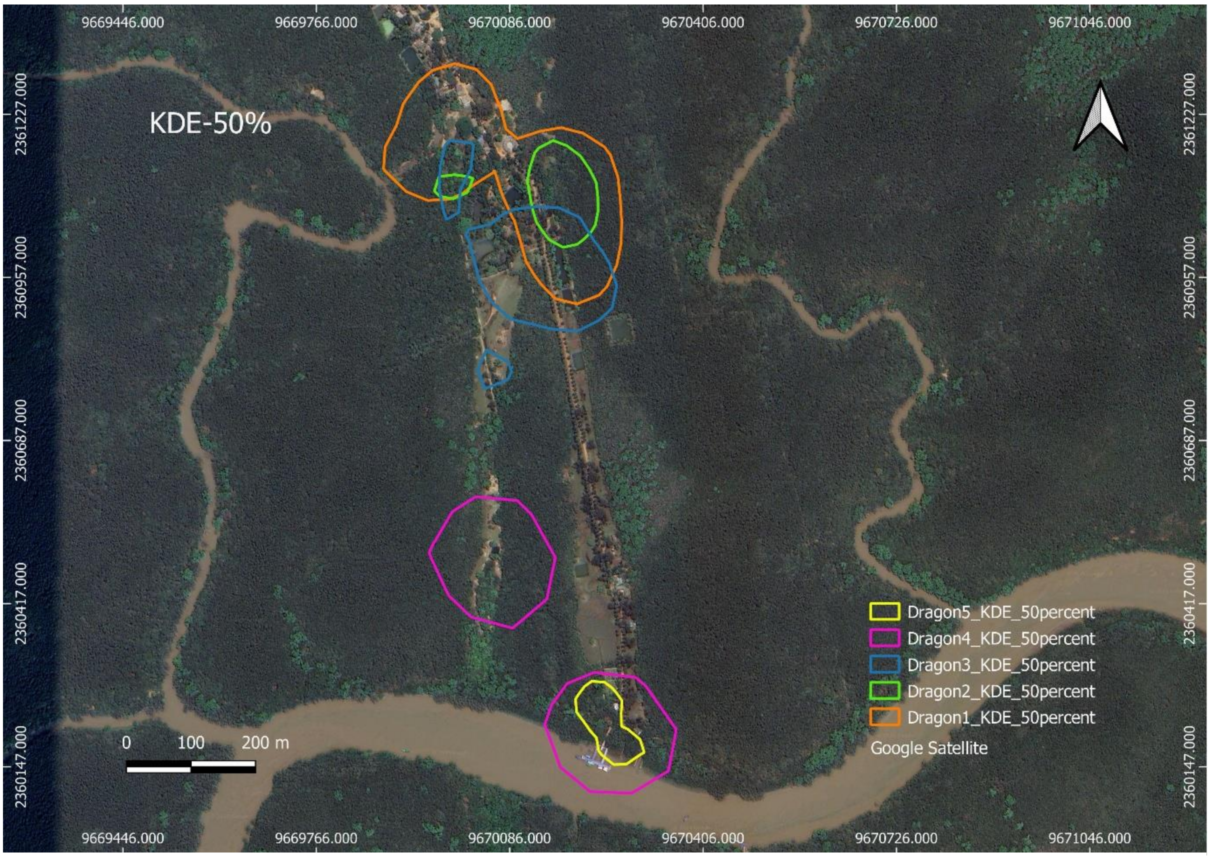


Fig. 15: 50% KDE overlap among 5 WMLs

Table 6: Activity area overlap in between WMLs in both 95% and 50% KDE

95% Activity Range Overlap

Dragon Pair	Overlap Area (Ha)
Dragon 1 vs Dragon 2	7.595578
Dragon 1 vs Dragon 3	14.071292
Dragon 1 vs Dragon 4	1.029471
Dragon 1 vs Dragon 5	0.000000
Dragon 2 vs Dragon 3	6.695982
Dragon 2 vs Dragon 4	0.231818
Dragon 2 vs Dragon 5	0.000000
Dragon 3 vs Dragon 4	1.174285
Dragon 3 vs Dragon 5	0.000000
Dragon 4 vs Dragon 5	3.500619

50% Core Activity Range Overlap

Dragon Pair	Overlap Area (Ha)
Dragon 1 vs Dragon 2	1.691255
Dragon 1 vs Dragon 3	2.244333
Dragon 1 vs Dragon 4	0.000000
Dragon 1 vs Dragon 5	0.000000
Dragon 2 vs Dragon 3	0.695112
Dragon 2 vs Dragon 4	0.000000
Dragon 2 vs Dragon 5	0.000000
Dragon 3 vs Dragon 4	0.000000
Dragon 3 vs Dragon 5	0.000000
Dragon 4 vs Dragon 5	0.810455

At very few instances two of the tagged lizards were seen together within 50mt, dragon 1 and 2 were caught and released in the same location, in the capturing process of dragon 4 we found dragon 3 was also at the exact location. The other occurrences of dragon 4 and 5 can be explained by the overlap of their activity ranges. But, still other dragons(1, 2 & 3) to have a significant overlap, where spatio-temporal was never seen.

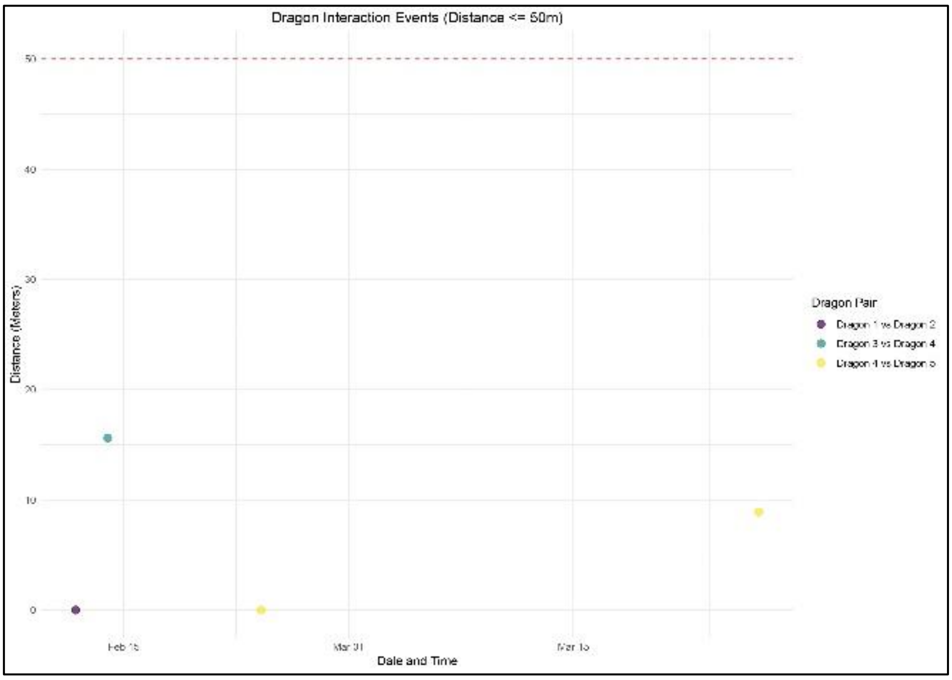


Fig. 16: Spatio-temporal overlap between WMLs

Behaviour pattern

Behaviour was plotted against relative humidity and ambient temperature to visualize a pattern in the activity and scatter plot (Fig 19) explains the peak of certain behaviours visualized during the study period.

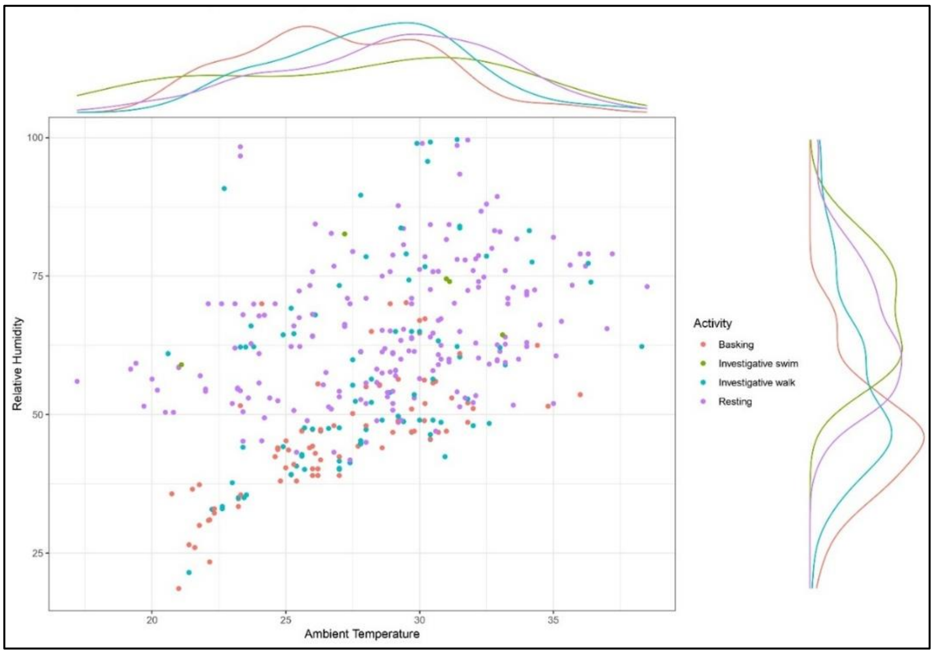


Fig. 17: Preferred activities across a range of Ambient temperature and relative humidity

To see the influence of substrate/vegetation on behaviour, I've done Fisher's test to see the significance between environmental factors and the behaviour. A total of three behaviours (investigative swim was removed due to insufficient data) were plotted against Substrate/Vegetation with number of counts on the y-axis using a bar plot (Fig 20). Using standard residuals of the chi-square test, we've also estimated the expected value of occurrences of certain behaviour that could happen in specific substrates/vegetation and plotted it in a heat map (grey area in Fig 21 has no estimate). Red (positive values) represents positive interaction, and blue (negative values) is vice versa between environmental variables and behaviour.

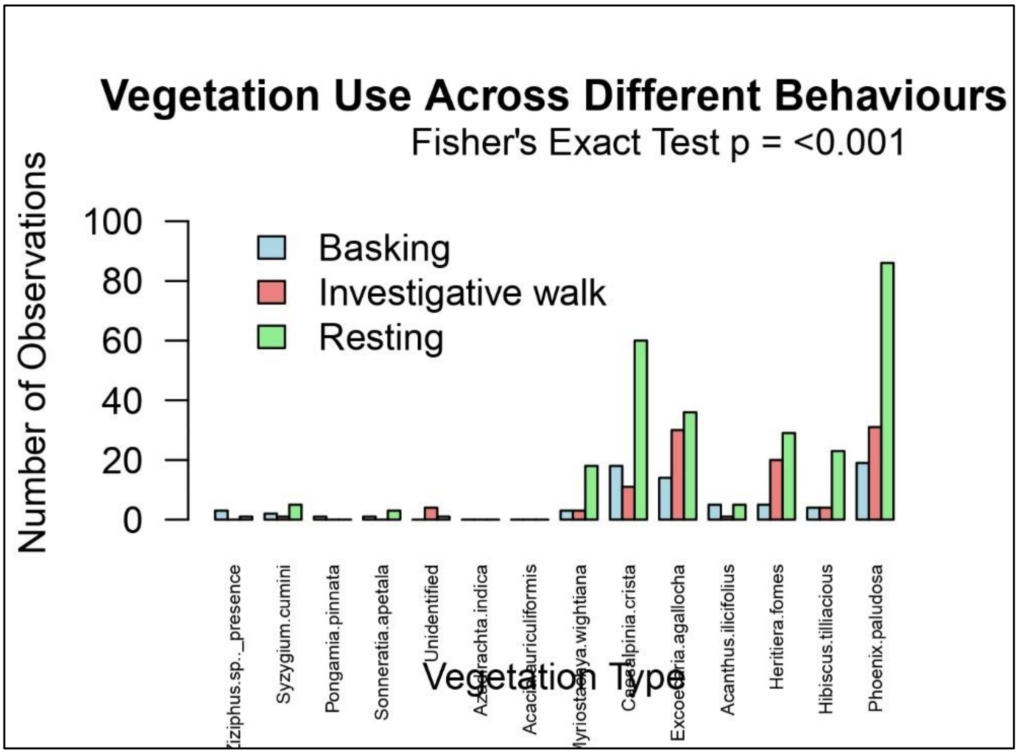


Fig. 18: Shows vegetation preferences for a specific activity

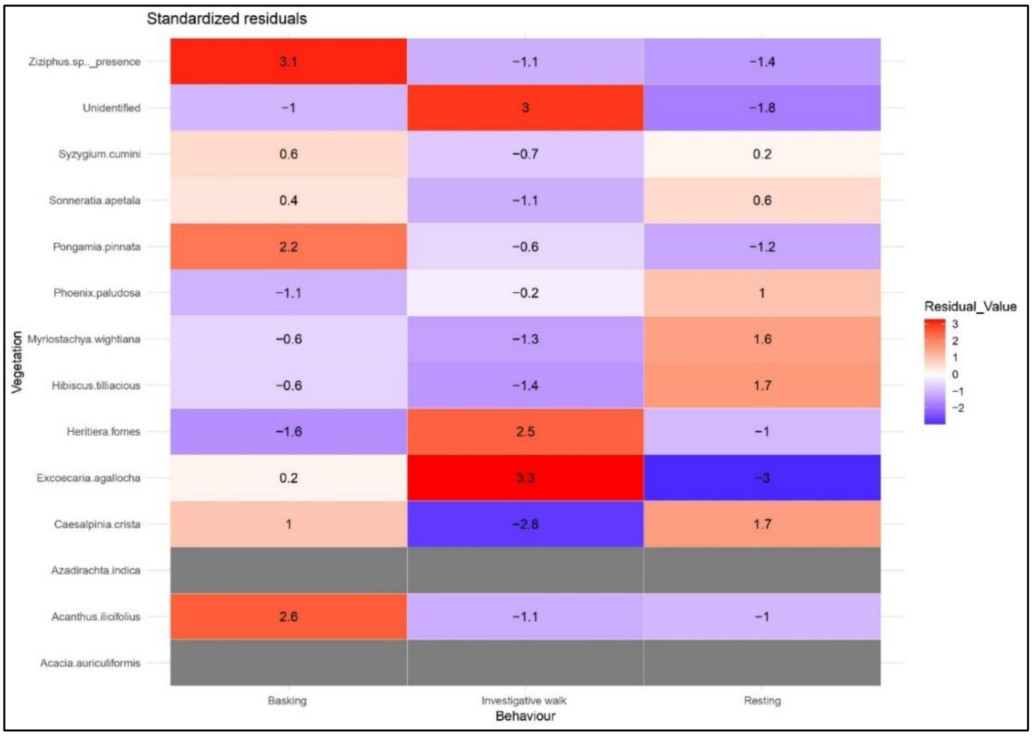


Fig. 19: Expected observation of behaviour in the respective vegetation patch

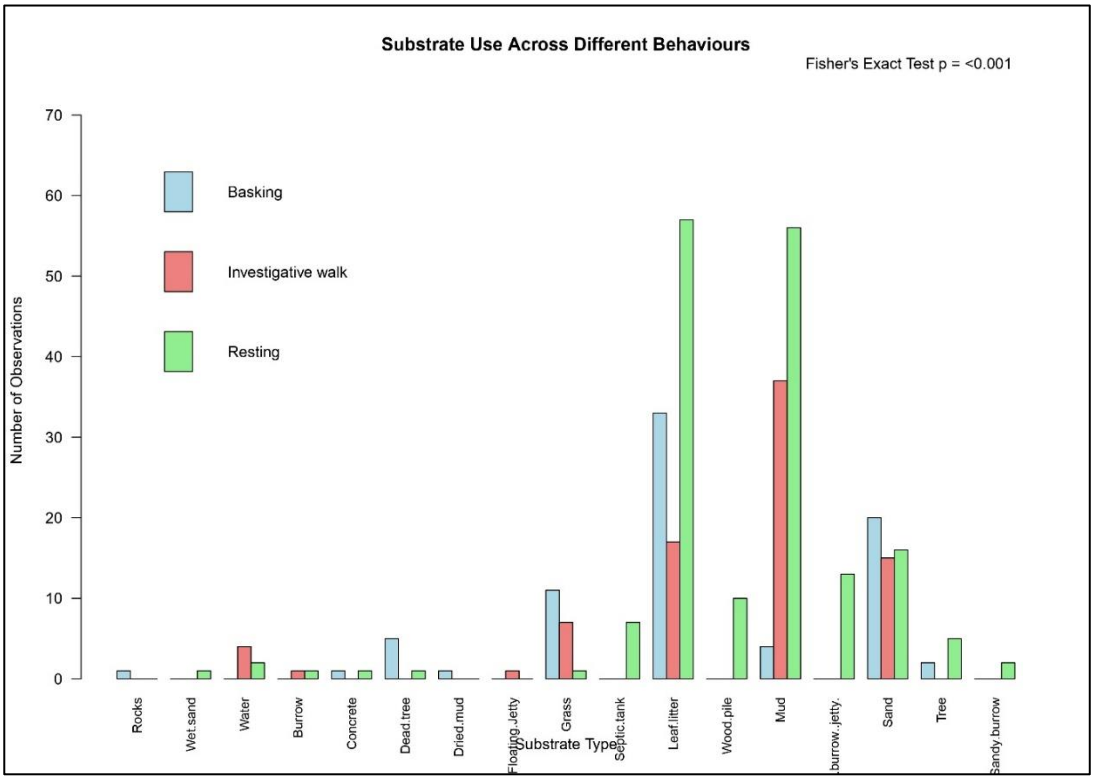


Fig. 20: Shows substrate preferences for a specific activity

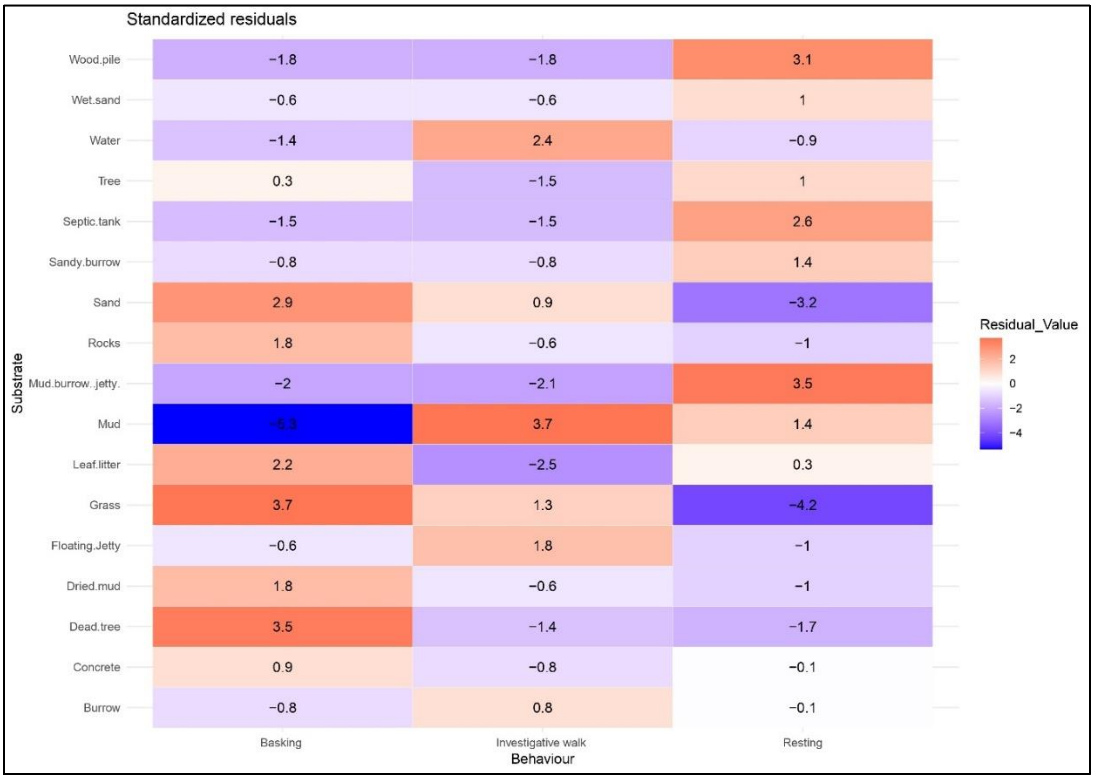


Fig. 21: Expected observation of behaviour in the respective substrate

To see how far these lizards venture from vegetation, the distance to vegetation cover and different behaviours were plotted in a box and jitter plot. To derive a statistical result Kruskal-Wallis test was done, and the results were P=0.631, which shows no significant (P<0.05) difference between behaviours and distance to vegetation. All the activities are associated close to the vegetation (very clear from Fig. 22), hence we can say these lizards occasionally venture out.

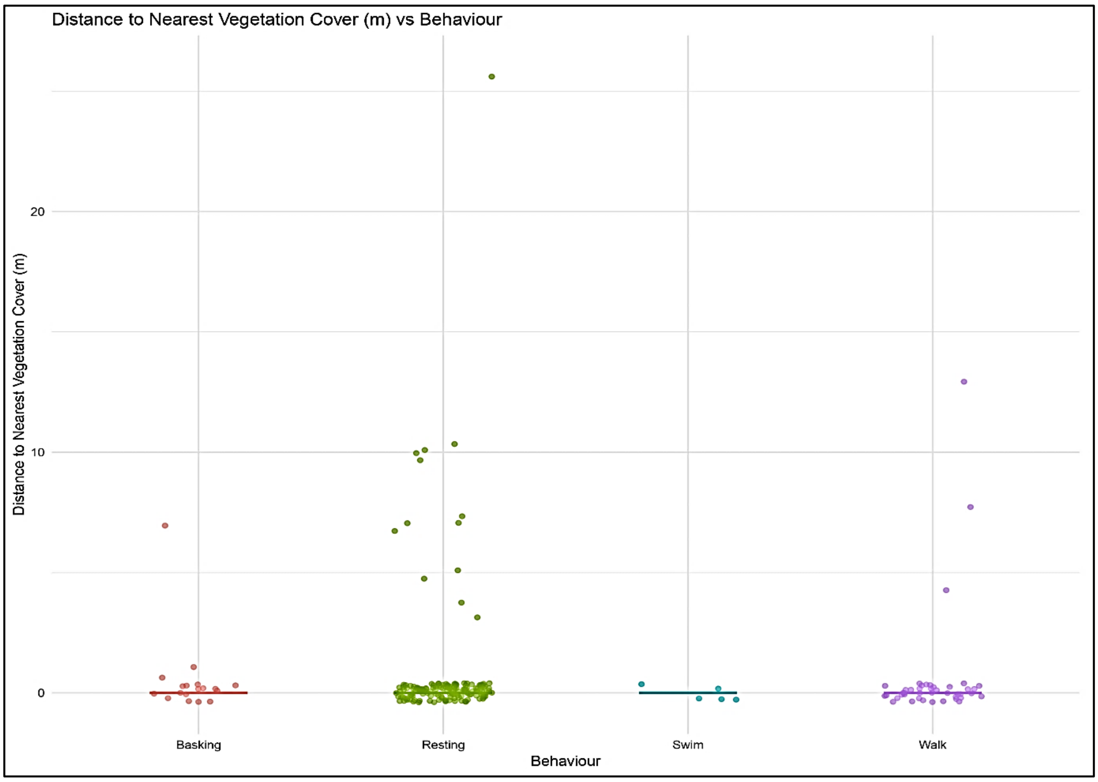


Fig. 22: Graph showing the preferred behaviour with respect to distance to vegetation

Table 7: Results of the Kruskal-Wallis test for distance to vegetation cover and behaviour

Metric	Value
Chi−squared	1.723
Degrees of Freedom (df)	3
P−value	p=0.6318

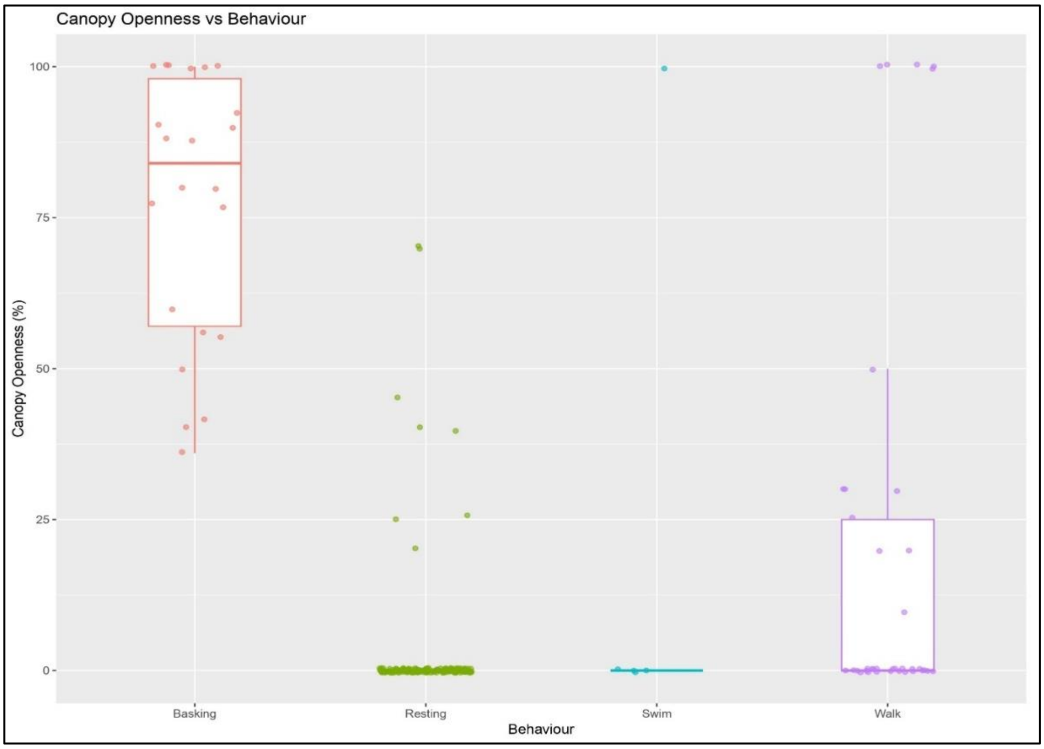


Fig. 23: Graph showing the preferred behaviour with respect to canopy cover

Table 8: Results of the Kruskal-Wallis test for canopy openness and behaviour

Metric	Value
Chi−squared	122.691
Degrees of Freedom (df)	3
P−value	p<0.0001

Table 9: Results of the post-hoc(Dunn's test) for canopy openness and behaviour

Comparison	Z_Value	P_Adjusted
Basking − Resting	10.825	p<0.0001
Basking − Swim	4.066	p=0.0001
Resting − Swim	−0.993	p=0.9622
Basking − Walk	6.455	p<0.0001
Resting − Walk	−3.978	p=0.0002
Swim − Walk	−0.580	p>0.9999

To check the influence of canopy openness on the behaviour of WMLs, I tried the same box and jitter plot with canopy openness on the Y-axis and behaviour on the X-axis. Kruskal-Wallis test showed higher significance (P=0.0001) in the relation between canopy openness and behaviour. To see how each behaviour differs from the others, a Dunn's test with pairwise comparison was made, and the results showed basking differs significantly from other behaviours, which means it was done in more open canopy areas while the other behaviours were preferred in closed canopy areas.

DISCUSSION

Movement pattern

In the tracking period of two months (February 16 – April 16), WMLs movement is mostly dependent on the foraging ground. Similar to WML *V. komodoensis* movements were also related to their feeding strategy (Auffenberg 1981). In our study area, WMLs mostly prefer to stay near the forest edges, rather than forested areas. As the major part of their diet consists of dead chitals, they navigate to the location of the carcasses, and that's where the longest movement occurs, at least for most of it. Similar to home range, the larger individuals have larger distances covered in a day. The interesting part of the study was that none of the VHF-tagged animals visited the area of capture/release, though there is food supplementation. But it's not the case with other monitors, which we've captured during the same process; some of them showed up at the same place within 45 minutes.

From Fig. 4-8, it is seen that the lizards return to the same patch several times, most likely for a similar kind of activity. They show strong site preference; each WML has their resting, foraging and basking spots. As they move to different places, they choose a more suitable site for different activities within the patch. Sometimes, different individuals do share the same site, but at a different temporal scale. Dragon 1, 2, 3 and 4, 5 had the same site for resting, but none of them can be seen together; their activity varies temporally.

Activity range

The activity range calculated by KDE gives us an overview of the area used by WMLs in a span of two months. To do home range estimation in KDE, Seaman et al. suggested a minimum of 30–50 locations, while the suggestion of Girard et al. was even more stringent criteria, recommending at least 300 locations and this study got enough data points to fulfill Seaman's suggesstion.

The estimates we got in the activity area use for each WML varies with the weight of the individual monitors, larger the individual, more it moves and larger the area. If the animal is small, it has relatively a smaller activity range. Thus, based on the results of this study, we can see the relation between SVL and weight of the animal; the longest SVL(dragon 5) has the lowest weight, which is inappropriate, and it has the smallest activity range too.

The activity range estimated by 95% KDE is mostly defined by the foraging areas; similar strategies were observed in deciding the home range of *V. bengalensis* and *V. albigularis* (Auffenberg et al., 1991; Philipps, 1995). Most of the outlying points in the 95% isopleth were the foraging sites, as mentioned earlier, these WMLs venture out in search of chital carcasses, which makes major part of their diet, followed by crabs, and other dead animals. WMLs near the canteen area have a major food source, which is fish, crab, prawn waste and other leftover food. The same 95% KDE estimate shows places where WMLs can't access- the creeks and forest patches on the other bank. The possible reason could be that in Bhitarkanika National Park, the WMLs knew the present locations of saltwater crocodiles, which restricts them from stepping into any of the water bodies inside the park, because of this reason, crossing the creeks and accessing the forest patch on the other side seems impossible. They do cross creeks but only at the lowest tide, when there is no water. Which is why their home range is restricted by large creeks, which have water inundation for all seasons and at the lowest tide. 50% KDE shows the exact activity range of the monitors in my study period, and that can be considered as the observed activity range.

Fig. 24. A water monitor lizard next to a saltwater crocodile

All the tagged individuals shared their space with other WMLs without showing territoriality, and most of their foraging, basking and resting grounds overlapped with each other. Some of the long-term studies show that varanids do not form fixed home ranges and show very little territoriality with large overlap in their home ranges (Auffenberg, 1981, 1988, 1994). WMLs live a solitary life, but they can survive together in a place with a reasonably high resource potential, i.e., around active kitchens or in locations with carcasses, but still, the smaller ones are getting dominated by larger individuals.

Fig. 25: Individuals foraging on a carcass near a human habitat area

Behaviour

The routines of these lizards are always dependent on various environmental factors. Some of the factors play a major role in deciding their activities, while the rest support certain behaviour.

Vegetation is an important variable that always gets very little focus in most of the varanid-related studies. In a study conducted by EBLOpeng (2012), his results showed that WML are found in places with shrub cover. It could be possible because of the suitable habitat they find among shrubs. In my study area, too, they mostly preferred patches with dense undergrowth or shrub cover; the dominant shrub species in my ISA were *P. paludosa, C. crista,* and *A. illicifolius.* But in Wikramanayake and Dryden (1993) study on both *V. bengalensis* and *V. salvator* they found that neither of the species is confined to any vegetation type when actively foraging. Adding to the environmental variables, substrate helps in supporting the behaviour of these lizards. In this study, WMLs prefer more of *E. agallocha* and *H. forms* patch for investigative walk, where there is less canopy openness and the substrate is of mud, the reason is for foraging crabs. *E. agallocha* has almost no pneumatophores, which makes it easy to walk and hunt. When the tide is high, the crabs climb to the pneumatophores of *H. formes*, which are again more exposed to hunt.

When resting, the WMLs use a closed canopy, and the distance to vegetation remains always very less. There were some exceptional points in resting in Fig. 22. It is because, in the process of cooling themselves faster, they enter septic tanks or burrows in the jetty, which is a little away from the vegetation. When these lizards are done with their meal, they don't move from the resting ground for at least two to three days. Basking is mostly done in places with more canopy openness and near the mangrove edge, that's where these WMLs can escape threats

easily. To speed up the heating process, they choose either leaf litter or grass bed or something that could heat up faster as their substrate.

CONCLUSION

The results of the study are restricted to the adult male water monitor lizards during the non-breeding season. Total actual activity range of 5 monitors, KDE 50 % Dragon 1 - 6.90 (ha), Dragon 2 - 1.51 (ha), Dragon 3 - 3.92 (ha), Dragon 4 - 5.69 (ha), Dragon 5 - 0.76 (ha). As these animals venture for foraging, the KDE 95% is estimated based more on the outlying points. With the help of regression analysis, we can interpret that the size of the activity range is governed by the size of the animal. Also, the WMLs had a large overlap and didn't show any territoriality, which could be explained by the subsidised resources available in the human-dominated area. The overlap with the human-dominated area is mainly for foraging purposes, followed by resting in septic tanks and occasional crossings between forest patches. In this study, we got preferences for the vegetation patch and its associated behaviour, also most the activities are closer to the vegetated area.

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APPENDIX

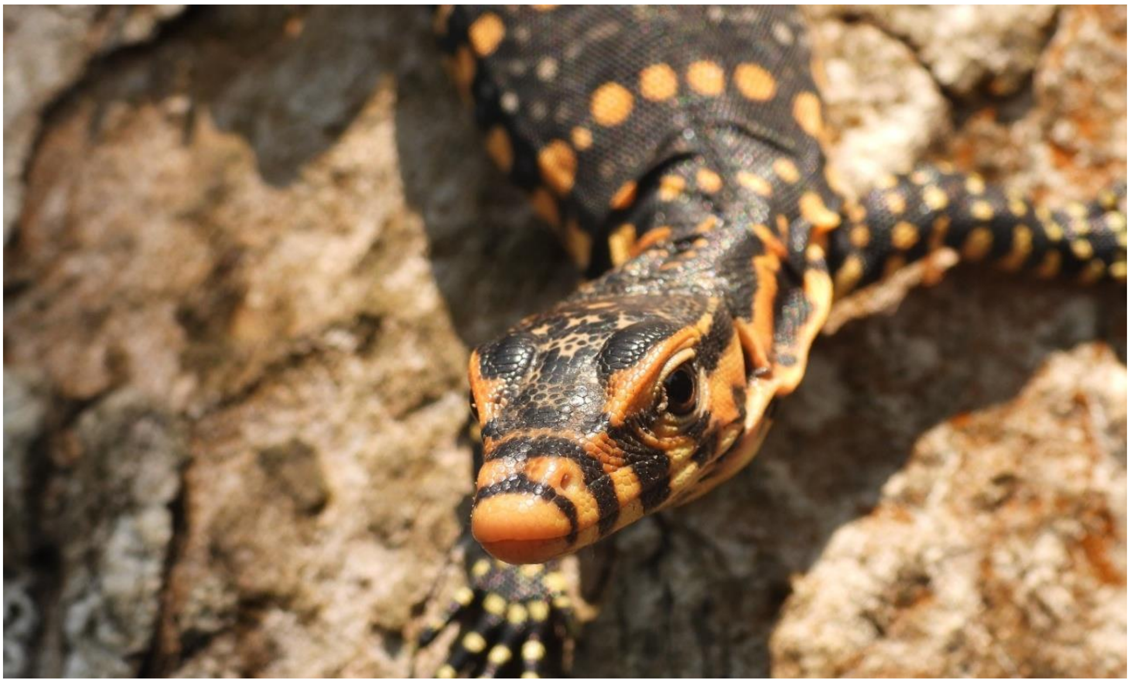

Image 9: A hatchling of WML

Image. 10: WML is entering a septic tank to rest

Image 11: Vomit of a WML

Image 12: WML is eating a fish head

Image 13: Food subsidised area (behind canteen)

Image 14: VHF-tagged WML resting in *P. paludosa* patch

Image 15: VHF-tagged water monitor in a vegetation patch

Image 16: Swimming WML