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Williams, Rhiannon Carys

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Translocation of a Medically Important Snake: Russell's Vipers (*Daboia russelii*) in Rural India

Rhiannon Carys Williams
500408364

bsu6f0@bangor.ac.uk

rhiannonwilliams97@gmail.com
School of Natural Sciences, Bangor University, Bangor, LL57 2UW, Wales

Project Supervisors: Dr Wolfgang Wüster & Dr Xavier Glaudas

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I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. All other sources are acknowledged by bibliographic references. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree unless, as agreed by the University, for approved dual awards.

Yr wyf drwy hyn yn datgan mai canlyniad fy ymchwil fy hun yw'r thesis hwn, ac eithrio lle nodir yn wahanol. Caiff ffynonellau eraill eu cydnabod gan droednodiadau yn rhoi cyfeiriadau eglur. Nid yw sylwedd y gwaith hwn wedi cael ei dderbyn o'r blaen ar gyfer unrhyw radd, ac nid yw'n cael ei gyflwyno ar yr un pryd mewn ymgeisiaeth am unrhyw radd oni bai ei fod, fel y cytunwyd gan y Brifysgol, am gymwysterau deuol cymeradwy.

Abstract

Snakebite is a neglected tropical disease that disproportionately affects poor and rural communities, causing 58,000 deaths annually in India alone. High frequency of human-snake interaction in a highly anthropized environment is a large contributor to this figure. To combat conflict, snake rescue is often used. Rescued snakes are subsequently translocated to a receiver site. However, their movement ecology and longevity are not assessed post-release. Reviews of translocation, mostly in temperate environments, largely concluded that snakes were unsuitable for rescue translocation. These studies concluded that translocation results in aberrant movement patterns, decline in body condition and increased mortality. However, tropical snakes experience differing selection pressures. Translocation research in India has been limited to one king cobra. Given the medical significance of snakebite in India, an understanding of the effect of translocation on more medically impactful snakes would be of immense value. In this study the effect of translocation on male Russell's vipers (*Daboia russelii*) is compared to a control group of resident snakes using radiotelemetry. *D. russelii* are probably the largest contributor to snakebite in India. The effect of environmental (temperature and rainfall) variables was also assessed.

Movement patterns (average daily movement, mean distance per movement, movement frequency and motion variance) and home range estimates (Dynamic Brownian Bridge Movement Models) were calculated for seven control and seven translocated snakes over the full tracking term and between seasons. No statistical difference was found between translocated and resident snakes apart from in movement frequency and core range. Movement increased between the monsoon and the post-monsoon season, probably as a result of the males' mate searching. However, limited longevity and body condition data suggests that, though translocation does not obviously impact snakes' movement patterns, it may influence the health of individuals and their behavioural ecology. No relationship was found between rainfall data and movement patterns. However, movement increased as temperature increased.

If further research demonstrates limited effect on the health and movement ecology of medically important snakes, this will be very positive as translocation is a widely employed tool in conflict resolution and to reduce the impact of snakebite. However, if deleterious effects are found, there is an argument for increased focus on other snakebite prevention strategies e.g. community outreach and provision of protective gear.

Introduction

Snakebite and Conflict

The World Health Organisation (WHO) recognises snakebite as a neglected tropical disease (WHO, 2017, 2018, 2019). Snakebite is particularly problematic in developing countries like India (Harrison *et al.,* 2009). Although it is difficult to quantify the true extent of the problem, global estimates suggest that there are circa 2.68 million venomous snake bites per annum, causing serious injuries (disabilities, amputations etc.). Approximately 138,000 of these occur in India alone. Estimates suggest that circa 125,000 deaths occur annually, roughly 58,000 of which occur in India (Chippaux, 1998; Kasturiratne *et al*., 2008; Mohaptra *et al*., 2011; Suraweera *et al.,* 2020).

There are various drivers for both snakebite and snakebite mortality hotspots in regions such as India. The most obvious factor influencing snakebite incidence is the frequency of human-snake interactions, which is particularly high in anthropized areas such as agricultural settings (Chippaux, 1998; Mohaptra *et al*., 2011; Suraweera, 2020). A large contributor to mortality following snakebite cases is poor access to effective treatment (Harrison *et al.,* 2009).

Complete avoidance of snake-human conflict is impossible. However, there is direct correlation between increased snakebite mortality and agricultural activity (Harrison *et al.,* 2009). In India, agricultural workers are at most risk of snakebite (Mohaptra *et al.,* 2011). Snakes are probably attracted to agricultural fields and human habitation due to the increased presence of rodents in those locations (Pandey *et al.,* 2016; WHO, 2019).

The risk of snakebite is increased by lack of infrastructure, e.g., floor-level beds, and a lack of appropriate clothing, e.g., absence of robust footwear. Consequently, there is also direct correlation between increased mortality and lower GDP and governmental expenditure, resulting in snakebite widely being considered as a disease of the poor (Harrison *et al.,* 2009).

Russell's vipers (*Daboia russelii*) are included as members of the "Big Four". This term is used to describe 4 species of medically important snakes that are widely considered to be the main contributors to snakebite mortality in India; the Indian cobra (*Naja naja*), the common krait (*Bungarus caeruleus*), the Russell's viper (*Daboia russelii*) and the saw-scaled viper (*Echis carinatus*) (Laxme *et al.,* 2019). Although there are disputes over the epidemiological value of this umbrella term, the status of *D. russelii* as the greatest cause of snakebite mortality in India is widely accepted (Mohaptra *et al*., 2011).

Daboia russelii are large, heavy-bodied vipers that are widespread throughout the Indian subcontinent (Whitaker and Captain, 2015). They are found in open grassy areas, scrub jungle, forest edges, rocky hillocks, dense thorny hedgerows and mangrove edges (*ibid*). *Daboia russelii* are also closely associated with heavily anthropized, agricultural habitat. Their abundance in agricultural habitat and their cryptic nature as ambush predators contributes to their medical significance (Figure 1). Many of the bites that occur in rural India are on the hands and legs and occur whilst the bite recipient is performing manual work e.g., harvesting and maintaining crops, cutting grass and weed clearing (Ghosh *et al.* 2016**;** Martin *pers. comm.*, 2019).

Figure 1. Study snake (TR10) demonstrating the effective crypsis of Russell's vipers (*Daboia russelii*).

As a result of the high incidence of snakebite in rural areas and the serious epidemiological implications of a *D. russelii* bite, many people have a deep-seated fear of these snakes. *Daboia russelii* envenomation can cause severe local necrosis, nephrotoxicity, haemotoxicity and neurotoxicity (Warrell, 1989, 2010; Chauhan and Thakur, 2016, Figure 2).

Figure 2. Result of a Russell viper (*Daboia russelii*) bite within the study site in rural Karnataka, Mysuru district. Credit: Gerard Martin

This fear is reflected in the many alternative names that are given to *D. russelii* and the folklore that surrounds them. In Kannada, they are often referred to as Kolaku Mandala, or "Breath of Death" (Juliet *pers. comm.,* 2019). This name probably originated from the necrotic nature of *D. russelii* bites (Figure 2). In South India, folklore includes the belief that any contact with *D. russelii* can cause necrosis (Juliet *pers. comm.,* 2020), including the snake's saliva or breath. Due to this fear, they are often persecuted and killed. Many snakes are burned or buried once they are killed (Figure 3).

Figure 3. Russell's viper (*Daboia russelii*) killed within the study site. Left: Study Snake (T7) beaten to death. Right: Snake in fire in field filled with livestock.

Due to the medical significance of snakebites, great research effort has been directed at antivenom treatment and efficacy (Bhaumik, 2016; Maduwage *et al*., 2016). However, little has been invested in snakebite prevention strategies (WHO, 2019). The WHO outlined in its report that, in order to reduce the impact of snakebite, more work needs to be concentrated in prevention strategies, identifying that any successful snakebite prevention strategy must include research on community knowledge, socio-cultural understanding and perception of snakes. Targeted community education is a crucial element, taking a bottom-up approach to snakebite prevention by engaging the community and local leaders. Often measures that prevent other diseases are effective in snakebite prevention e.g.

mosquito nets serve as a physical barrier for snakes entering households at night (Chappuis *et al.,* 2007); and the use of boots whilst working, protect feet from bites as well as from diseases as a result of infection due to open wounds (WHO, 2019).

Translocation

One focus of prevention strategies is to reduce snake-human conflicts. Attempts to reduce conflict frequently involve snake rescue and translocation schemes. Such schemes involve the collection and relocation of "nuisance" snakes by licensed snake rescuers. Translocation efforts appear to reduce conflict significantly, reducing both snake mortality and the risk of a bite when untrained individuals attempt to subdue or kill the snake. As a result, mitigation translocation has become a widely used and publicly popular management strategy (Kingsbury and Attum, 2009; Sullivan *et al*., 2014).

The popularity of the strategy and the success of some population-level translocations have led both the public and many conservationists to believe it can be widely and effectively used in human-wildlife conflict resolution (Sullivan *et al.,* 2014). However, little research has been conducted in countries like India, where snakebite is rife, to assess either the effect of translocation on the animals moved or its efficacy as a mitigation strategy.

Multiple review articles have documented mixed success from translocations (Dodd and Seigel, 1991; Reinert, 1991; Fischer and Lindenmayer, 2000; Seigel and Dodd, 2002; Trenham and Marsh 2002; Germano and Bishop, 2009; Sullivan *et al.,* 2014). Of the varying translocation scenarios, rescues to reduce human-wildlife conflict appear to be the least successful (Fischer and Lindenmayer, 2000; Germano and Bishop, 2009).

There are two main methods of translocation: short distance translocation (SDT) and long-distance translocation (LDT). LDT involves translocation of an animal outside its understood home range, and SDT within it (Hardy *et al.,* 2001). LDT is often used in rescue translocations, as it is considered to be far more effective in

reducing human-animal conflict than SDT (Hardy *et al.,* 2001; Brown *et al.,* 2009; Sullivan *et al.,* 2014). With SDT many individuals return to their capture site. However, a wide body of research has found that there are problems associated with LDT (Dodd and Seigel, 1991; Reinert and Rupert, 1999; Plummer and Mills, 2000; Nowak *et al*., 2002; Butler *et al*., 2005a,b; Barve *et al,* 2013; Sullivan *et al.,* 2014). Documented negative impacts include altered and increased movement patterns, atypical behaviour, declines in body condition and increased mortality rates.

Landmark snake translocation studies have largely focused on temperate environments, and particularly on American rattlesnakes (Dodd and Seigel, 1991; Reinert and Rupert, 1999; Plummer and Mills, 2000; Nowak *et al*., 2002). Several other taxa have also been studied e.g., *Nerodia, Heterodon* and *Vipera berus* (Plummer and Mills, 2000; Roe *et al.,* 2010; Nash and Griffiths, 2018). Despite climate differences, rattlesnakes, as primarily rodent-feeding, heavy-bodied vipers, have reasonably similar life-histories to *D. russelii* and therefore may serve as an indicator of expected effects to their movement patterns and survival expectations.

A study by Nowak *et al.* (2002) assessed the effects of translocation on Mohave rattlesnakes (*Crotalus scutulatus)* in two sites. On both sites, translocated snakes' average movement and range size increased significantly post translocation. On one site, where snakes had been translocated shorter distances, 50% of the snakes moved back to their capture site. They displayed atypical long linear, directional movements, characteristic of homing movements seen in many translocation studies (Dodd and Seigel, 1991; Reinert and Rupert, 1999; Germano and Bishop, 2009; Sullivan *et al.,* 2014). On the other site, there were also significantly higher movement patterns, with snakes out of their usual range more than 43% of the time. Snake health also declined, with an increased mortality rate (5/7 snakes), and a significant decline in condition of the recaptured snake. Increases in movement frequency and distance, and a decline in the health of the translocated snakes, were mirrored in a study of timber rattlesnakes (*Crotalus horridus*), where mortality was far higher in translocated snakes due to a failure to overwinter, disease and predation (Reinert and Rupert, 1991).

Translocated dugite (*Pseudonaja affinis*) were tracked and compared to resident snakes in Perth (Wolfe *et al.,* 2018). As in rattlesnakes, translocated snakes demonstrated greater activity ranges and lowered survivorship.

The effect of environmental variables is apparent in reptiles. As ectotherms, their body temperature is dependent on the thermal environment, making them especially sensitive to changes in the environment (Eskew and Todd, 2017). Seasonal variation has a significant effect on the spatial ecology of vipers, particularly in temperate environments. In temperate regions, snakes are constrained by ambient temperatures and the availability of sunlight (Gibbons and Semlitsch, 1987). This is reflected in many spatial ecology studies, such as in Massasauga rattlesnakes (*Sistrurus catenatus*) where snakes moved to upland prairie habitat between April and May, returning to the central prairies in the late summer to autumn in order to hibernate (Seigel and Pilgrim, 2002). Mortality as a result of failure to overwinter is a significant consequence of translocation efforts in temperate environments, especially with species that are habitat specialists e.g. rattlesnakes, where snakes were unable to locate appropriate hibernacula (Nowak *et al.,* 2002).

However, little research has been undertaken in Asia, where selection pressures on translocated snakes differ greatly. Despite rattlesnakes offering a useful comparison for potential movement patterns in *D. russelii*, temperate environments offer very different challenges to tropical environments. Temperate species are limited by seasonal differences to a greater degree than tropical species, which are less likely to be limited in their movement by the need to raise their body temperature (Shine and Madsen, 1996). However, tropical environments offer alternative pressures, as a result of increased seasonal rainfall (pre-monsoon showers and the monsoon) and humidity (Daltry *et al.,* 1998; Brown and Shine, 2002).

Limited Asian translocation studies include one on white-lipped pit vipers (*Trimerusurus albolabris*), another commonly translocated species (Devan-Song *et al.,* 2016). LDT in this species had negative impacts, leading to increased movement patterns, asynchrony in brumation cycles relative to local individuals

and reduced reproductive success. Translocated *T. albolabris* in the study were translocated from districts around China and released on the same conservation sanctuary, mirroring common translocation practices in the area (Devan-Song *et al.,* 2016). The release site was very different to the urban areas in which the snakes were found. Choice of unsuitable release sites is often considered a contributing factor towards translocation failure (Germano and Bishop, 2009; Devan-Song *et al.,* 2016).

The only Indian translocation study was undertaken on king cobras (*Ophiophagus hannah*); the study found that a translocated snake moved far greater distances daily compared to control snakes and had a greater home range (Barve *et al.,* 2013). They demonstrated similar aberrant movement patterns, homing behaviour and lowered expected survival (Barve *et al.,* 2013). However, *O. hannah* have very different life histories to *D. russelii*, utilising more restricted, forest habitat, demonstrating far larger home ranges and habitual use of the same features within their range e.g. burrows (Barve *et al.,*2013).

Habitat fragmentation is heavily implicated in the choice of unsuitable receiver sites in temperate environments, where urbanisation has significantly reduced suitable habitat (Hardy and Greene, 1999). Poor choice of receiver site has been implicated in the failure of many translocation efforts (Germano and Bishop, 2009). This is largely due to snakes, such as rattlesnakes, having relatively specific habitat preferences. In limited cases where LDT appears to have proved a successful mitigation strategy, the choice of suitable release sites away from anthropic activity appears to have been instrumental e.g. in timber rattlesnakes (Walker *et al.,* 2009) and anecdotally in black mambas (*Dendroaspis polylepis*), another habitat generalist (Litschka-Koen, 2009).

Site fidelity is well documented in reptiles (Row and Blouin-Demers, 2007). However, *D. russelii* are habitat generalists and are also closely associated with heavily anthropized, agricultural habitat. (Whitaker and Captain, 2015). Consequently, it is possible that translocated *D. russelii* would show greater

versatility and adaptability to suitable release sites compared to the results of previous studies.

Translocation in India also differs in key ways from rescue translocation in many temperate countries. Due to the high rate of human-snake conflict in India, snake rescue is heavily used. As a result, many local rescuers will undertake several rescue calls a day. Instead of releasing snakes immediately, it is typical for rescuers to keep snakes for several days before undertaking a LDT and releasing them all at the same receiver site. Given that snakes are sometimes also kept for several days in close quarters, there is also a risk of disease transmission and loss of condition prior to release (Martin *pers. comm.,* 2019).

Translocation in India appears to occur at alarming rates. Barve *et al.* (2013) conducted interviews with snake rescuers. One snake rescuer, "Snake Shyam" based in Mysore reported rescuing roughly 23,000 snakes between 1997 and 2010. He estimated that he translocated snakes 15-60 km. Therefore, if negative effects are found from LDT in India, the negative effect on snake populations may be very marked even if this figure is somewhat over-inflated.

Radio Telemetry

Advances in radio telemetry techniques, particularly implanted radio-transmitters, have been instrumental in improving the information available from snake movement ecology studies (Reinert, 1982; 1984; 1992). However, as aforementioned, there has been clear bias towards temperate regions particularly America, Europe and Australia (Shine and Pilgrim, 1996; Seigel and Pilgrim, 2002; Bauder *et al*., 2016; Rugerio *et al*., 2018; Wolfe *et al.,* 2018; Nash and Griffiths, 2018). Recently, studies in more neglected areas have increased, with studies undertaken in both Africa and South-East Asia (Glaudas and Rodriguez-Robles 2011; Mohammadi *et al*., 2014; Alexander and Maritz 2015; Devan-Song *et al.,* 2016; Maritz and Alexander 2016; Marshall *et al.,* 2019). These studies have aimed to reduce taxonomic bias in radio telemetry and to gain a better understanding of the spatial ecology of medically significant snakes.

Despite the taxonomic richness of Indian herpetofauna and the number of highly medically significant snakes, very little spatial ecology research has been carried out. Difficulty in getting permission to perform the invasive procedure of implanting the transmitters, procuring licences and permits and the expense of the equipment are probably contributing factors to this (Garton *et al.,* 2001; Peterson *et al.,* 2015). This is a time-consuming process which may also prove to be prohibitive.

The only spatial ecology studies that have been undertaken are from a small sample of *Ophiophagus hannah*, in Agumbe (Barve *et al.* 2013; Rao *et al*. 2013). Although highly venomous, *O. hannah* are not considered medically significant due to their elusive nature and comparatively limited interaction with people. The understanding of the general spatial ecology of medically significant snakes in India is poor. This is particularly concerning, given that India has the highest snake-human conflict ratio and snakebite incidence in the world (Chippaux, 1998; Kasturiratne *et al*., 2008; Mohaptra *et al*., 2011). Due to this, India is one of the largest utilisers of local snake rescuers to undertake conflict mitigation (Barve *et al.,* 2013). It is therefore alarming that the only study to assess the spatial ecology of a venomous snake in India, included only one translocated snake and this snake responded poorly to translocation treatment (Barve *et al.,*2013).

Steps have been taken to address this knowledge gap. A landmark study is currently underway at The Gerry Martin Project (TGMP), Rathnapuri, Karnataka on *D. russelii.* The study aims to understand the long-term spatial ecology of both resident and translocated *D. russelii.* Early work on this project has aimed to assess the effect of seasonality and sex on the movement of resident snakes (Kuttalam, 2020). Translocated snakes were all rescued and translocated over long-distances, snakes were rescued either by a TGMP snake rescuer, or Snake Shyam. Therefore, some of the unique aspects of Indian translocation were accounted for.

Preliminary work has also confirmed high incidence of people in close proximity to resident snakes in the study area, consistent with previous literature (Harrison *et al.,* 2009; Mohaptra *et al*., 2011). People were observed within ≤50m of snakes for 16.5% of over 2,000 tracking observations and ≤10m, for 5% of observations

(Glaudas, 2021). The true rate is likely higher as these figures don't account for non-tracked snakes. This data also supported an agricultural link with snake conflict (Mohaptra *et al.,* 2011), with the highest numbers of observations being of agricultural workers (47.6%). These figures highlight the representative nature of the study site, the high rate of human-snake interaction and the importance of incorporating spatial ecology into the understanding of snake bite incidence.

Study

In India, no study on the effects of translocation has been performed on one of the 'Big Four' species. As the most medically significant snake in India, it would be valuable to understand the effects of translocation on the movement patterns of *D. russelii*.

In order to assess this, radio telemetry was conducted in rural Karnataka, South India on resident and translocated snakes to compare their movement patterns. The short-term effects of long-distance translocation were assessed over an 8-month period. The effects of seasonality on the movement patterns of both resident and translocated snakes was also compared.

As the only telemetry study on heavy-bodied vipers in Asia, the study also served as an opportunity to use a novel model to estimate home range size (Kranstauber *et al.,* 2012; Silva *et al.,* 2018; 2020).

The main objectives were to:

1. Assess the effects of translocation on the movement patterns of translocated snakes compared to resident snakes.
2. Determine if seasonality affects the movement of translocated and control snakes differently.
3. Establish the effect of rainfall and temperature on the daily movement of snakes.

A difference in movement pattern or distance travelled when snakes are translocated may lead to human-snake conflict. Snakes will be released near

human habitation, as there is little pristine and isolated habitat available. If translocation does have a significant effect on Russell's viper behaviour, questions must be asked of the efficacy of translocation as a conflict prevention and conservation strategy and whether it would be more appropriate to focus on alternative conflict mitigation strategies e.g. community outreach and provision of protective equipment.

Methodology

Study Area

Radiotelemetry of Russell's vipers (*Daboia russelii*) was conducted on The Gerry Martin Project Farm (TGMP) in Rathnapuri, Hunsur, Karnataka and the surrounding area (12°14'16.7"N 76°20'05.2"E). The area is approximately 750 m above sea level and consists of heavily exploited agricultural land, with limited seminatural habitat remaining. The main habitat consists of seasonal farmed plantations e.g., rice, banana, areca nut, tobacco, corn, sugarcane, coconut, tapioca, turmeric, ginger, and various fruit and vegetable crops. There are also more marginal habitat types, including scrubland, grassland, and weeds e.g. congress grass (*Parthenium hysterophorus*). The waterways largely consist of open canals, irrigation ditches and lakes. The topography of the *D. russelii* release sites can be seen in Figure 4.

The climate is similar to that of the surrounding Mysore District. The hottest temperatures the district experiences are usually between 30°C to 35°C in April. The lowest temperature is experienced in December, at 20°C (Megahed and Srikantaswamy, 2020). The region typically receives most of its rainfall during the Indian summer monsoon season (June to September) which brings over 70% of the annual rainfall to India (Zhou *et al*., 2019).

Figure 4. Satellite image of The Gerry Martin Project and surrounding land, indicating the highly anthropized habitat in which control and translocated snakes were located (ArcGIS v10.6).

Radio Telemetry and Data Collection

Telemetry was undertaken by the author and other fieldworkers as part of the ongoing TGMP Russell viper radio telemetry project. Eleven rescued snakes were translocated and released at TGMP and in surrounding areas. Translocated snakes were obtained from snake recues carried out in neighbouring areas and were released in areas outside of their understood home ranges. Release sites were chosen based on habitat suitability, ensuring that there was sufficient refuge, without obvious human activity (Wolfe *et al*., 2018).

Radio transmitters with a 12-month lifespan (model SB-2, 5.0g, Holohill Ltd.) were surgically implanted into the coelomic cavity of an anaesthetised snake by a licensed veterinarian according to accepted published procedures (Reinert and Cundall, 1982; Reinert, 1992; Glaudas and Rodrĺguez-Robles, 2011; Figure 5). Transmitters were less than 3% of the body weight of the animals, to limit impact on their movement (Nowak *et al.,* 2002; Glaudas and Rodriguez-Robles, 2011). Snakes were released 1-day post implantation at their translocation site to allow for recovery (Reinert and Rupert, 1999; Brown *et al.,* 2009). During surgery, the mass and morphometrics (Snout-Vent length, Tail Length, Head Length and Head Width (mm) of each snake was recorded (Figure 5).

Figure 5. Transmitter implantation and morphometric measurement being undertaken during surgery.

Ethical assessment of both surgical and tracking procedures was undertaken as part of the permit from the Karnataka Forestry Department and Bangor University's research protocol. Each surgical procedure was observed by a forest department official and random visits were made to ensure the rigour of the tracking procedure.

Only adult snakes were used to avoid possible confounding effects of ontogenetic variation. All translocated snakes used in the study were male to control for the effects of sex, due to a limited sample size. Previous studies have demonstrated that male viperids display greater average daily movements, greater distance per movement and greater activity ranges than females (Anderson, 2010; Glaudas and Rodriguez-Robles, 2011; Devan-Song, 2014; Kuttalam, 2020). Some studies have also demonstrated that females may respond better to translocation treatment, displaying less aberrant movement patterns (Nash and Griffith, 2018).

The movement of translocated snakes was compared to that of male resident snakes that were being tracked as part of the existing telemetry project. Resident (control) snakes were collected during local rescues and released at, or near, their collection site serving as a useful measure of how snakes would move within their normal home range, producing control home ranges and movement patterns.

Tracking of snakes occurred over an 8-month period between April and November 2019. Where logistically possible, each snake was tracked daily. Tracking was undertaken using a radio receiver (DJ-X11, Alinco Inc.) and a directional H antenna (HB9CV, Andreas Wagener Telemetrieanlagen). Universal Transverse Mercator (UTM) coordinates were taken at the release site and when individuals moved, using a GPS (Garmin GPSMAP 64). Data collection occurred in the field using Open Data Kit Collection software v1.28.4 (ODK Collect). Data points were plotted to identify any outliers which were then cross-checked, with any erroneous points removed from the dataset (Supplementary Material). The full tracking period of each snake can be found in Appendix A in addition to the cause of the snakes' removal from the study e.g. death or loss of signal. Environmental data was also collected at TGMP (Figure 6). Daily rainfall was measured twice a day using a rain gauge. Temperature was taken using a datalogger (tempnote) which took 144 readings each day. Due to equipment constraints, temperature data was only taken between the 13th of April and the 23rd of October.

Home Range Analysis

Radio telemetry study is a fast-developing field and analysis is undergoing a rapid change. The most effective method for home range analysis is often debated. Traditional home range analysis methods usually involve Minimum Convex Polygons (MCPs) and Kernel Density Estimators (KDEs).

MCPs are generated to give a rough estimation of total range. MCPs offer a comparison of space use. However, they can be inaccurate. They are often criticised for showing Type I (underestimation of areas used and oversmoothing) and Type II (overestimation of area used and undersmoothing) errors (Laver and Kelly 2008; Fieberg and Börger 2012; Silva *et al.*, 2018). The size of the MCP activity range is also sensitive to the number of telemetry points in the analysis (White and Garrot, 1990; Reinert, 1992).

MCPs are not considered a useful metric for habitat use. KDEs are a more useful metric of home range size and habitat use, as they allow prediction of the likelihood of finding an animal in a specific area within its home range (Powell, 2000; Millspaugh and Marzluff, 2001). Kernels provide a more biologically relevant comparison of habitat use. They emphasise areas of higher use, as opposed to simply encompassing all the data points. They therefore allow analysis of the core areas within the kernel. 100% MCPs also give an unrealistic estimation of home range size due to the disproportionate effect of an outlier (Kenward, 2000). 95% KDEs are produced to estimate the total home range, 5% outlier removes the most disparate points and increases the precision of home range estimation (Ujvari and Korsos, 2000; Powell, 2000; Barve *et al.,* 2013). 50% KDEs give a useful indication of core movement patterns and habitat use within the wider home range (Reinert and Rupert, 1999; Ujvari and Korsos, 2000; Barve *et al.,* 2013, Wolfe *et al.,* 2018). However, KDEs also display Type I errors when analysing large datasets and Type II errors where the dataset is small (Fieberg and Böger, 2012; Silva *et al.*, 2018; 2020).

Methodology must vary based on the spatial ecology of the study species. Row and Blouin-Demers (2007) highlighted issues with producing biologically relevant

KDEs for herpetofauna, as traditional methods generate inconsistent and often overestimated home range sizes, depending on the smoothing factor used (Seaman and Powell, 1996; Powell, 2000). Traditional methods are inappropriate for vipers as they assume that there is no spatial autocorrelation between relocations, an assumption which fails as they move very little.

Dynamic Brownian Bridge Models (dBBMMs) are increasingly used in home range analysis (Kranstauber *et al.,* 2012; Silva *et al.,* 2018; 2020). dBBMMs help improve accuracy in the analysis of home ranges for GPS telemetry by creating a one-dimensional fix-frequency independent behavioural measure (Kranstauber *et al.,* 2012). Additionally, dBBMMs do not require *a priori* knowledge of animal movements, where this is needed to correct KDE smoothing (Silva *et al.,* 2018; 2020). Studies comparing dBBMMs to traditional MCP and KDE methods for herpetofauna movement patterns found dBBMMs had lower error rates, even where data sets were lower resolution (Silva *et al.,* 2018; 2020). However, dBBMM studies were not compared to autocorrelated KDE models. Silva *et al.* (2018) looked at data for king cobras (*Ophiophagus hannah*) which have far different life histories compared to heavy-bodied vipers. Large elapid snakes are active foragers with greater daily movement and, as such, display less autocorrelated data (Barve *et al.,* 2013; Silva *et al.,* 2018).

An alternative model produces KDEs as a Continuous-Time Stochastic Process (CTSPs) as opposed to discrete time-correlated random walk models using the ctmm package in R (Calabrese *et al.,* 2016). CTSPs allow for inferences on relocation data, independent of sampling constraints and accommodate for autocorrelations that are likely to occur in viper movement data sets. However, archetypal data modelled using dBBMMs, displayed low error rate in ambush predators with both long/short term sheltering periods and long/short movements, which would correspond to projected *D. russelii* movement ecology (Whitaker and Captain, 2015; Silva *et al.,* 2020).

Data Analysis

Straight line distances were calculated in ArcGIS v10.6.1 (ESRI, 2018) for each movement to calculate Average Daily Movement (ADM), Mean Distance per Movement (MDM) and Movement Frequency using the Point Distance function. The average daily movement was calculated by averaging the distances for each day tracked, including days of immobility. Mean distance per movement was calculated for each individual by dividing the sum of their straight-line distances with the number of days where movement occurred. Movement frequency was calculated as the percentage of days where movement occurred.

Independent sample *t*-tests were conducted to assess if there was any significance in the difference between the movement variables of control and translocated snakes over the complete period tracked. All statistical analysis was undertaken in IBM SPSS Statistics v.26 (IBM Corp, 2019). Where necessary, data was transformed to meet assumptions of normality (Field, 2013). Where parametric assumptions were violated, appropriate non-parametric tests were utilised (Field, 2013). Due to the small sample size, sequential Bonferroni *p*-value corrections were undertaken to test for false positives and to reduce Type I errors over multiple analyses (Holm, 1979; Rice, 1989; Field, 2013).

Movement variables were also compared between seasons to assess if there was significant difference in movement between control and translocated snakes across seasons using a two-way ANOVA. Seasons were determined based on published literature and separated into Pre-Monsoon (April – May), Monsoon (June – September) and Post-monsoon (October - November) (Zhou *et al.,* 2019; Megahed and Srikantaswamy, 2020).

However, 2019 proved unusual in terms of climate with late pre-monsoon showers and a late monsoon that retreated the latest it ever has in India, extending into the first weeks of October (NASA Earth Observatory, 2019). The monsoon was also characterised by depauperate and stochastic rainfall, with low rainfall in June and July followed by a deluge in August, accounting for most of the rain (Figure 6). To

assess the effect of rainfall on movement patterns, correlation between daily rainfall and sum daily movement was analysed. Rainfall raises ambient humidity. While snakes are unlikely to expose themselves to direct precipitation, they may be more active on the subsequent more humid day (Eskew and Todd, 2017). To account for this, the difference between movement on days where rainfall occurred and movement the day after rain was analysed. The relationship between temperature and sum daily movement for each group was also analysed. Due to the nonparametric nature of both the rainfall and environmental data, Spearman's correlations were undertaken.
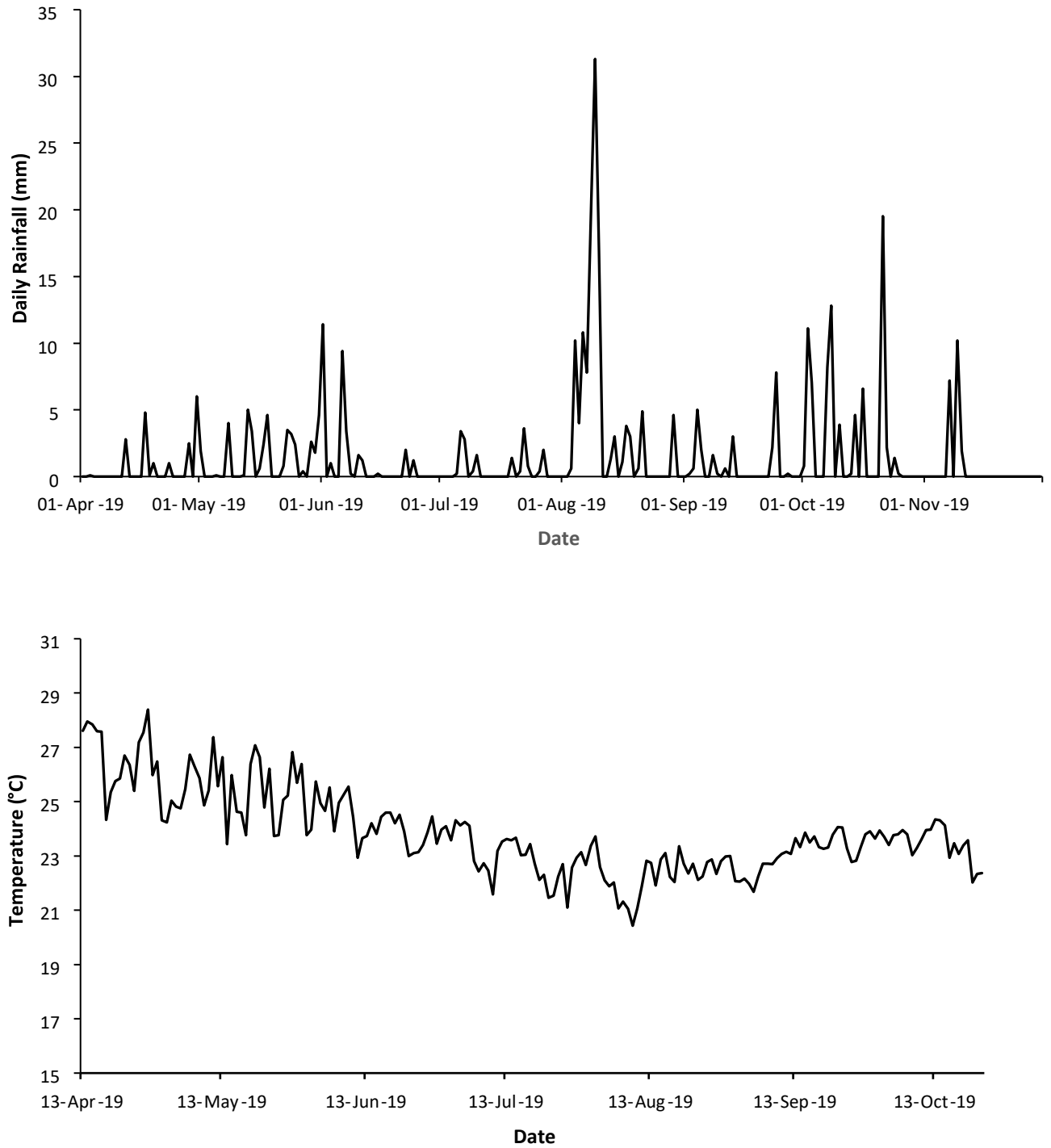
Figure 6. Above: Average daily rainfall (mm) collected using a rain gauge located at The Gerry Martin Project between April and November 2019. Below: Average daily temperature (°C) measured using a datalogger (Temp Note) between April and October 2019.

Brownian motion variance (σ^2m) was also calculated as an estimate of the snakes' mobility using R Studio v. 1.3.959 (Horne *et al.,* 2007; R Core Team, 2020). Motion variance provides quantifiable data on the linearity of a path and the extent that it varies in speed and scale of movement (Kranstauber *et al.*, 2012). Higher σ^2m values suggest that an individual displayed increased activity and/or irregular paths. To calculate the motion variance, a window size of 15 and a margin of 7 were set based on guidance in Kranstauber *et al.* (2012). Home range analysis was then undertaken in R using the move and adehabitatHR package. Three isopleths were used (50%, 95%, 99%) to gain a more complete comparison of varying home range sizes. The 50% isopleth was used to estimate the core range of an individual, indicating the areas of greater intensity of use e.g. shelter sites. 95% and 99% isopleths were used to provide an estimate of activity area (Samuel *et al*., 1985; Wilson *et al.,* 2010; Silva *et al.,* 2018). Analysis was also undertaken on each of these estimates to assess the significance between translocated and control groups and the effect of season.

Motion variance and home range estimate calculation workings can be found in the RScript in the supplementary material. The R packages used were 'ggplot2' (Wickham 2016), 'scales' (Wickham and Seidel 2019), 'dplyr' (Wickham *et al*., 2020), 'move' (Kranstauber *et al.,* 2020), 'adehabitatHR' (Calenge 2006), 'ggspatial' (Dunnington 2020), 'rgeos' (Bivand and Rundel 2019), 'stringr' (Wickham 2019) and 'ggmap' (Kahle and Wickham 2013).

Results

11 translocated snakes and 7 control snakes were part of the telemetry project and were assigned IDs chronologically by capture date. However, as a result of mortality, 4 translocated snakes were not included in the analysis due to insufficient data. Snakes used for analysis are indicated in Table 1. A summary of the data used in the analysis and the statistical output can be found in Appendix B.

Table 1. Number of data points collected for control (T) and translocated (TR) snakes per season including dates tracked. Snakes marked with an asterisk indicate individuals where insufficient data was available for further analysis.

ID	Sex	No. of Data Points Collected				Start Date	End Date
		Pre-Monsoon	Monsoon	Post-Monsoon	Total		
T1	M	49	95	39	183	13/04/2019	18/11/2019
T4	M	47	96	38	181	13/04/2019	18/11/2019
T7	M	48	95	8	151	13/04/2019	09/10/2019
T8	M	48	97	39	184	13/04/2019	18/11/2019
T12	M	27	93	35	155	04/05/2019	18/11/2019
T15	M	14	31	0	45	18/05/2019	20/07/2019
T18	M	4	92	29	125	28/05/2019	18/11/2019
TR2*	M	12	0	0	12	13/04/2019	23/04/2019
TR3	M	48	12	0	61	13/04/2019	12/06/2019
TR4	M	39	75	0	114	23/04/2019	30/08/2019
TR5	M	30	100	48	178	02/05/2019	18/11/2019
TR6	M	29	100	49	178	02/05/2019	18/11/2019
TR7	M	0	32	44	76	08/08/2019	15/11/2019
TR8	M	0	22	49	71	09/09/2019	18/11/2019
TR9*	M	0	0	22	22	17/09/2019	08/10/2019
TR10	M	0	0	46	46	04/10/2019	18/11/2019
TR11*	M	0	0	23	23	26/10/2019	18/11/2019
TR12*	M	0	0	24	24	26/10/2019	18/11/2019

Movement Patterns

A) Average Daily Movement

The independent samples *t*-test for average daily movement (ADM) did not demonstrate any significant difference between the movement of control and translocated snakes (t_{12} = 0.562, *P* = 0.585; difference = 1.804, 95% C.I. = -5.191 to 8.799) (Figure 7). A log 10 transformed two-way ANOVA displayed no significant interaction between group and season ($F_{(2,25)}$ = 2.034, *P* = 0.152). A post-hoc Tukey HSD analysis showed that snakes moved significantly further (*P* = 0.001) between the monsoon (13.38±1.73 m) and post-monsoon season (34.43±5.57 m). However, the statistical power of all analyses was affected by the small sample size of each group (N=7) and the varying number of data points available for each snake within seasons (Table 1, Appendix BI).
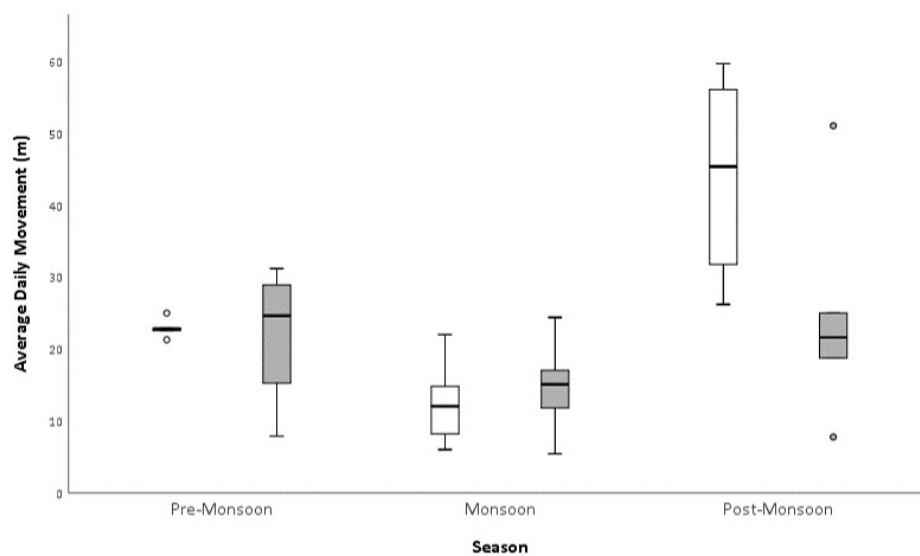
Figure 7. Average daily movement (m/day) whisker plots of control and translocated Russell's vipers (*Daboia russelii*) across seasons. White indicates control snakes, and grey translocated. Boxplots display the interquartile range (box) and median (line). The whiskers display the maximum and minimum values. Outliers are represented by dots.

B) Mean Distance per Movement

A Welch's independent samples *t*-test (parametric assumptions violated) for mean distance per movement (MDM) did not show statistical significance between translocated and control snakes ($t_{6.881}$ = -1.979, *P* = 0.089; difference = -19.246, 95% C.I. = -42.327 to 3.836). Despite the *p*-value lying just above the conventional significance threshold, the data is likely biologically significant with translocated snakes demonstrating a wider variation in MDM and greater MDMs (Figure 8).

Kruskal-Wallis analysis (parametric assumptions violated) provided strong evidence of a difference (*P*< 0.001) between the mean ranks of at least one pair of groups. Dunn's pairwise tests (adjusted with Bonferroni correction) demonstrated a significant increase in MDM between the monsoon (36.11±3.75m) and post-monsoon (100.3±12.61m) period in both the control and translocated group (*P*< 0.001) like in the ADM analysis.
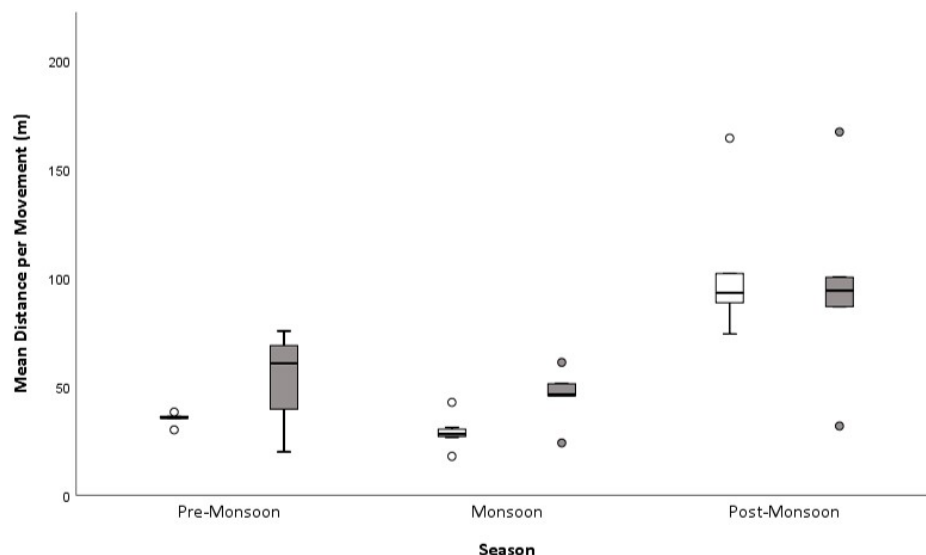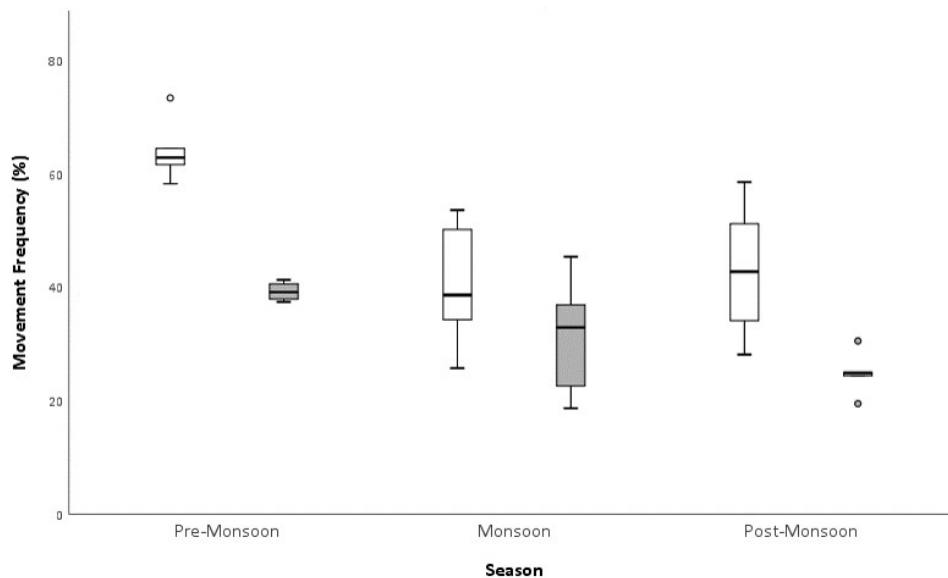

Figure 8. Mean distance per movement (m/move) of control and translocated Russell's vipers (*Daboia russelii*) across seasons. White indicates control snakes, and grey translocated. Boxplots display the interquartile range (box) and median (line). The whiskers display the maximum and minimum values. Outliers are represented by dots.

C) Movement Frequency

An independent samples *t*-test for movement frequency was undertaken. Control snakes (45.62%) demonstrated a greater movement frequency than translocated snakes (29.29%) as seen in Figure 9 (t_{12} = 3.856, *P* = 0.002; difference = 16.331, 95% C.I. = 7.104 to 25.557). ANOVA analysis showed no significant interaction between group and season ($F_{(2,25)}$ = 1.914, *P* = 0.169). Post-hoc analysis demonstrated significantly greater movement frequency in the pre-monsoon (53.15%) compared to the monsoon (33.98%) season (*P*< 0.001).

Figure 9. Movement Frequency (% days moved) of control and translocated Russell's Vipers (*Daboia russelii*). White indicates control snakes, and grey translocated. Boxplots display the interquartile range (box) and median (line). The whiskers display the maximum and minimum values. Outliers are represented by dots.

D) Motion Variance

Graphs generated for Brownian motion variance can be found in Appendix C. Despite translocated snakes showing greater variance (Figure 10), a Welch's independent *t*-test demonstrated no significant difference in motion variance ($t_{8.264}$= 1.378, *P* = 0.204, difference = -0.261, 95% C.I. = -0.695 to 0.173). A log-transformed ANOVA did not reveal a significant interaction between season and group ($F_{(2,25)}$ = 1.390, *P* = 0.587). Post-hoc analysis demonstrated increased variance from the monsoon (0.24±0.06) to the post-monsoon (1.48±0.40) season (*P* = 0.001).
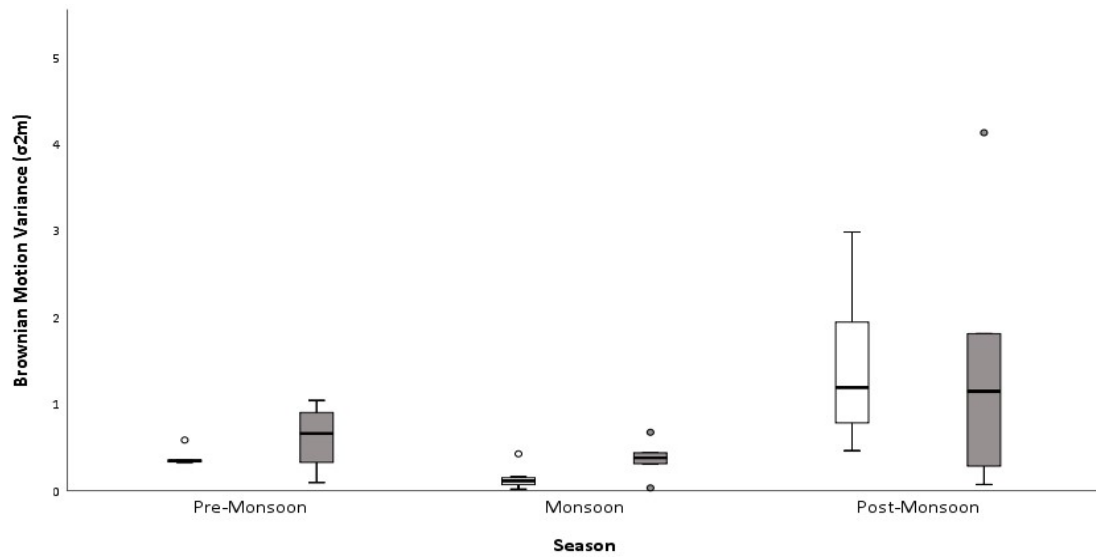
Figure 10. Brownian Motion Variance (σ^2m) of control and translocated Russell's Vipers (*Daboia russelii*). White indicates control snakes, and grey translocated. Boxplots display the interquartile range (box) and median (line). The whiskers display the maximum and minimum values. Outliers are represented by dots.

Home Range Estimates

Home ranges were produced for each snake for the full data collection term and per season. An overview of the data is shown in Table 2. Additionally, maps including the 3 dynamic Brownian bridge movement model (dBBMM) isopleth polygons were produced for each control and translocated snake for the full term and per season (Appendix D). No significant difference was found for the 50% dBBMM ($t_{12} = 1.506$, $P = 0.158$; difference = 0.13, 95% C.I. = -0.058 to 0.318), 95% dBBMM ($t_{12} = 0.560$, $P = 0.586$; difference = 1.307, 95% C.I. = -2.999 to 5.073) and 99% dBBMM polygon home range estimates ($t_{12} = 0.319$, $P = 0.756$; difference = 1.543, 95% C.I. = -9.016 to 12.101).

Table 2. Mean home ranges (ha) ± S.E.for dynamic Brownian Bridge Movement Model (dBBMM) estimations (dBBMM50%, dBBMM95%, dBBMM99%) between control and translocated groups and per season.

ID	Season	No. of Specimens	dBBMM50%	dBBMM95%	dBBMM99%
Control	Full Year	7	0.27±0.08	4.48±1.30	9.70±3.28
Control	Pre-Monsoon	5	0.20±0.04	1.82±0.31	2.77±0.45
Control	Monsoon	7	0.13±0.03	1.82±0.63	3.01±1.07
Control	Post-Monsoon	5	0.71±0.29	8.08±3.67	12.76±5.58
Translocated	Full Year	7	0.14±0.04	3.44±1.32	8.16±3.57
Translocated	Pre-Monsoon	4	0.15±0.07	1.77±0.57	2.86±0.79
Translocated	Monsoon	5	0.12±0.04	1.3±0.37	2.54±0.59
Translocated	Post-Monsoon	5	0.04±0.01	6.37±3.28	12.56±6.12

Log-transformed ANOVA results for the 50% dBBMM polygon indicated a statistically significant interaction between the effects of season and group ($F_{(2,25)}$ = 4.258, P = 0.026). Significant interaction was found between groups (P = 0.003) but not season (P = 0.508), demonstrating that both groups responded differently to the seasons as is demonstrated in the mean home ranges (Figure 11). The core range of translocated specimens decreased in the post monsoon season (0.04±0.01), whereas the control snakes range increased (0.71±0.29).

Both 95% ($F_{(2,25)}$ = 0.116, P = 0.891) and 99% ($F_{(2,25)}$ = 0.148, P = 0.863) polygons displayed no significant interaction between group and season, with post-hoc analyses displaying a significant increase in range between monsoon and post-monsoon seasons (P = 0.017, P = 0.014 respectively). Figure 12 shows home range maps for each group for the full tracking term and by season.
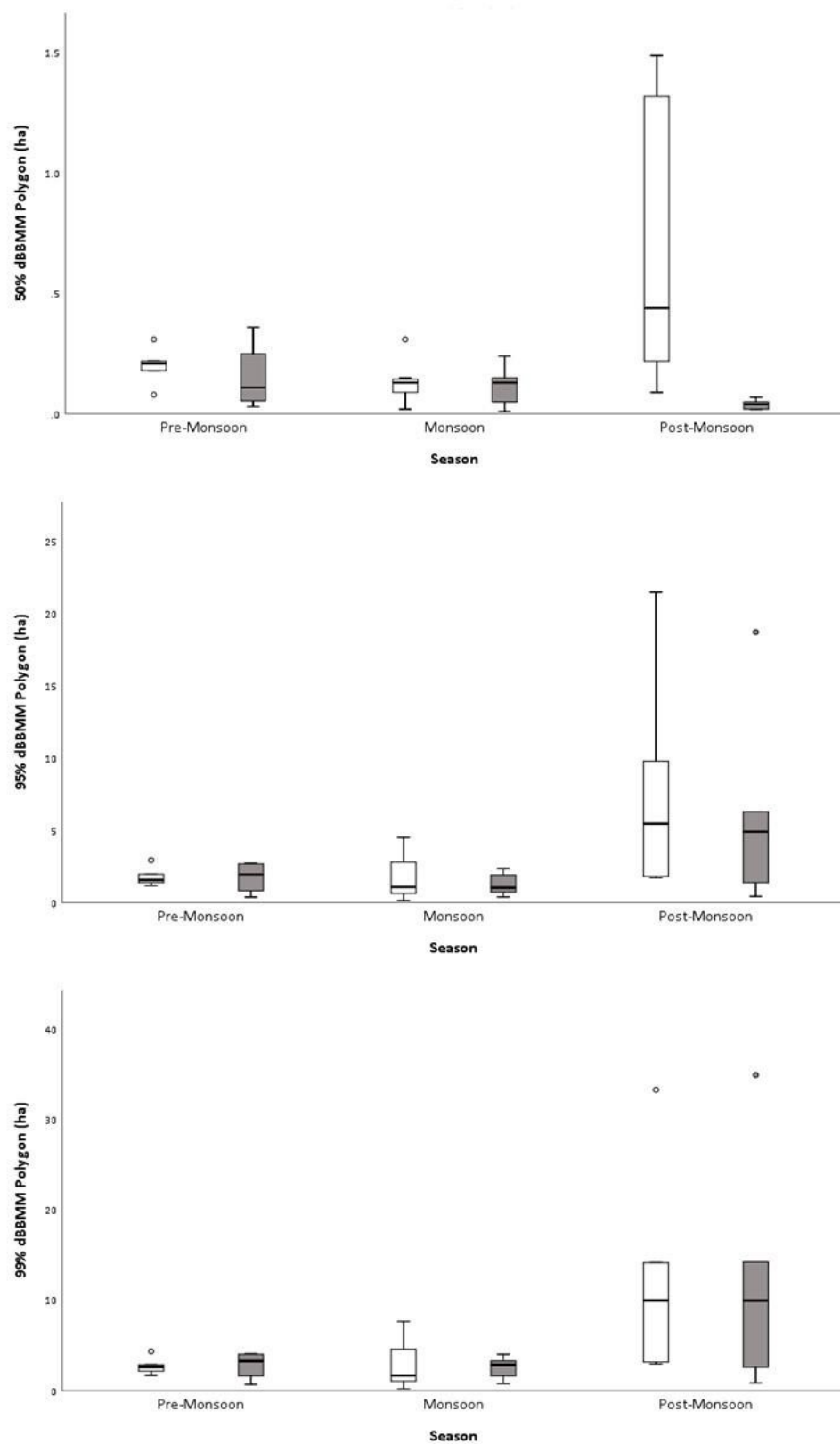
Figure 11. 50, 95 and 99% dynamic Brownian bridge model movements (dBBBMM) polygon home range estimates in hectares (top to bottom) for control (white) and translocated (grey) Russell's vipers (*Daboia russelii*). Boxplots display the interquartile range (box) and median (line). The whiskers display the maximum and minimum values. Outliers are represented by dots.
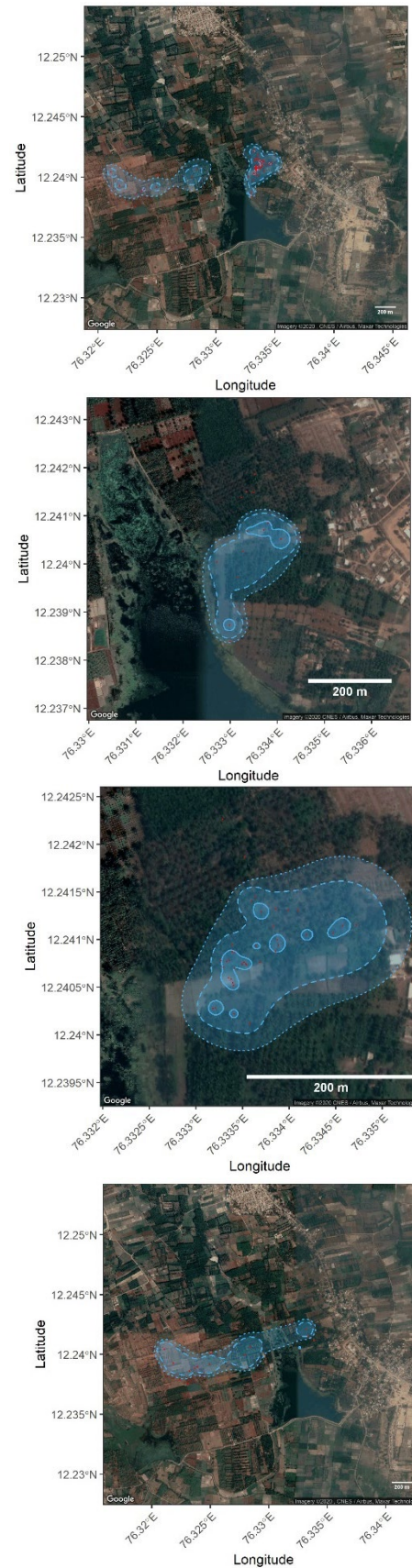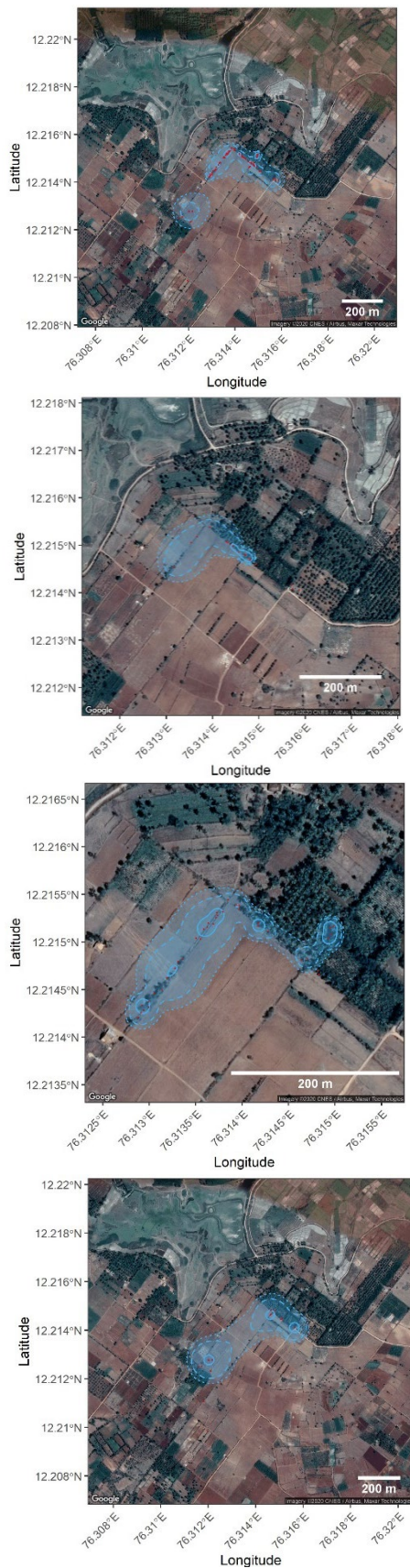
Figure 12. Dynamic Brownian Bridge Movement Model (dBBMM) home range estimates for the full term and per season. Two study individuals are depicted, control (Left, T12) and the other translocated (Right, TR6). Top to bottom: Full Term, Pre-monsoon, Monsoon & Post-monsoon. The core range is depicted by a solid line (50%) and activity ranges (95 & 99%) are depicted by the large and small dashed lines, respectively. Each red dot symbolises a unique relocation.

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Environmental Effect on Movement

Spearman correlation was undertaken to assess the relationship between daily rainfall and sum daily movement as the data violated parametric conditions. No significant correlation was found between rainfall and movement for either the control (r_s = -0.063, N =218, P = 0.353) or translocated (r_s = -0.073, N =218, P = 0.284) group. Correlation analysis was also undertaken to assess the effect of rainfall on movement the day after rainfall. Again, no significant correlation was found between control (r_s = 0.039, N =128, P = 0.661) and translocated snakes (r_s = 0.052, N =128, P = 0.557).

Spearman correlation was undertaken to examine the relationship between daily movement and daily mean temperature. A significant positive correlation was found between temperature and movement for the control (r_s = 0.281, N = 192, $P<$ 0.001) and translocated snakes (r_s = 0.342, N = 192, $P<$ 0.001); indicating that as the temperature increases, movement also increases.

Discussion

Although caution must be exercised in the extrapolation of the results due to small and unequal season sample sizes, some significant patterns emerge (Appendix B). Due to a sample size of only 7 snakes in each group, the sample size may be too small to detect the true effect of translocation as it's common to observe high variability in the spatial ecology of wild snakes (Putman *et al.,* 2013; Heiken *et al.,* 2016). Unlike movement data for the monsoon, the pre-monsoon and post-monsoon data was collected in a relatively short period of a month and thus may be more impacted by outliers.

Groups

I)   **Movement Variables**

Average daily movement, mean distance per movement and motion variance showed no significant difference between groups. No significant difference was reported between the control and translocated snakes apart from in movement frequency, where over the full tracking period control snakes demonstrated greater movement frequencies. This is in opposition to many studies that find a significant

increase in movement in translocated snakes (Dodd and Seigel, 1991; Reinert and Rupert, 1999; Plummer and Mills, 2000; Nowak *et al.*, 2002; Butler *et al.*, 2005a,b; Barve *et al,* 2013; Sullivan *et al.,* 2014; Wolfe *et al.,* 2018). If true, the lack of significant effect of translocation bodes well for translocation as a snakebite mitigation strategy. This is positive in a country like India where there is a high prevalence of snakebite conflict and translocation is a very widely used tool (Barve *et al.,* 2013).

Daboia russelii are heavy-bodied, ambush hunters and as such lead sedentary lifestyles (Whitaker and Captain, 2015). The low motion variance in both groups reflect this. Heavy-bodied vipers require safe long-term shelters to digest prey-items, during which time energy requirements reduce availability for active lifestyles (Silva *et al.,* 2018).

D. russelii are also habitat generalists and as such are likely to be well suited to translocation to a variety of sites, including the heavily agricultural receptor sites used in this study (Whitaker and Captain, 2015). Despite that, many of the snakes came from more anthropized areas. Therefore, their ecology may make them more suitable for translocation treatment, with receptor sites proving more suitable than their original home ranges. This is in opposition to landmark studies with heavy-bodied vipers that are habitat specialists e.g. rattlesnakes which fare poorly (Dodd and Seigel, 1991; Reinert and Rupert, 1999; Plummer and Mills, 2000; Nowak *et al.*, 2002).

However, some caution must be taken in the extrapolation of these results. Many of the translocated snakes used in this study were not translocated within 24 hours of capture. Several snakes were captured by the same snake rescuer and kept with many other individuals, often with many snakes in the same enclosures (including a mix of species) with the view of releasing them en masse in a single receptor site. Although using snakes that have been captured in this manner most accurately emulates the conditions of the majority of snake translocations in rural South India, the risk of infection and injury is markedly increased (Barve *et al.,* 2013).

Two of the translocated snakes used in the study (TR5 & TR8) both demonstrated a steady decline in condition during their time in the field and ultimately passed away. A parasite (Nematoda) was found in the glottis of TR5, leading to the

conclusion that parasite loads lead to declining condition in these individuals, as has been demonstrated in previous literature (Jacobson, 2007). Although the effect of parasite load varies across snake taxa, many snake species exhibit decreased growth rate and a decline in body condition (Madsen *et al.*, 2005; Ujvari and Madsen, 2006; Sperry *et al.,* 2009).

The decline in body condition of the snakes led to a decrease in movement with both individuals moving very little once their condition decreased significantly. Radio transmitters have shown to have little effect on the condition of snakes in previous studies (Sperry *et al.,* 2009). This body-condition related decrease in movement likely contributed to the lower movement frequency observed in translocated snakes.

It is possible that parasites were contracted by the translocated snakes as a result of their captive conditions. Poor captive conditions, particularly of multiple species and at high density has been known to suppress immune response and cause increased endo and ectoparasitic loads (Rajesh *et al.,* 2015). Parasite load can also be exacerbated by stress in captive animals, as stress also serves as an immunosuppressant (Mader, 1996; Wright and Mader, 1996; Rataj *et al.,* 2011). Given that all the snakes kept in close proximity were also wild-caught, the likelihood of the presence of an endoparasitic load is higher (Radhakrishnan *et al.,* 2009; Rataj *et al.,* 2011; Kavitha *et al.,* 2014a,b). Reptiles may harbour parasites for a long period of time before displaying signs of disease, and it may take time before the development of evident infection or loss of body condition (Fowler and Miller, 2004).

Previous research has been conducted to assess if the implantation of radio transmitters in snakes caused increased stress and whether it resulted in increased parasitic load (Sperry *et al.,* 2009). Radio-transmitters have shown to have little effect on the condition of snakes in previous studies, either from the implantation process or from repeated interaction during the tracking process. This is seemingly supported in this study, with none of the resident snakes demonstrating detrimental parasitic loads.

However, the stress of translocation may have increased translocated snakes' susceptibility to infection. A study on SDT showed no major effects on levels of the stress-related corticosterone and testosterone levels in rattlesnakes, (Holding *et*

al., 2014). However, LDT is more likely to expose an individual to chronic stress as a result of a combination of factors e.g. introduction to a novel environment, capture, handling etc. (Dickens *et al.,* 2010; Heiken *et al.,* 2016). In several taxa, there is evidence that multiple stressors can have additive effects (McFarlane and Curtis, 1989; McKee and Harrison, 1995). As such a combination of the aforementioned may have led to the high parasitic load.

II)   Home Range Estimates

No significant interaction between group and season was found during *t*-test analysis apart from in the 50% polygon home range estimate, likely as a result of the post-monsoon season (Figure 12).

In both groups *D. russelii* demonstrated small home ranges and core areas. As aforementioned this is likely as a result of the sedentary ecology of the snakes (Whitaker and Captain, 2015; Silva *et al*., 2018). This was also supported by field observations, where individuals were observed using shelter sites for extended periods of time with minimal movement.

Seasonality
I)   Movement Variables

Average daily movement and mean distance per movement displayed a significant increase from the monsoon to the post-monsoon season. No significant difference was found between the pre-monsoon and monsoon period apart from in movement frequency, where greater frequency was displayed in the pre-monsoon.

The increase in movement between the monsoon and the post-monsoon season is likely the result of the cessation of the monsoons and the resulting climatic changes (Zhou *et al.,* 2019; Megahed and Srikantaswamy, 2020). However, this increase in movement is reflected in distance moved, not movement frequency.

The increase in movement is likely the result of climatic changes coinciding with the mating season. This is confirmed by anecdotal observations made when tracking e.g. male combat, courtship and mating behaviour. During the post-monsoon period, 5 of the control snakes were observed paired with females for several days. None of the translocated snakes were observed engaging in mating activity. Although the study used a limited number of snakes, this may serve as an indicator that though the snakes' movement ecology was not significantly affected, their behavioural ecology was impacted negatively.

Long ranging movements are well-documented in male vipers when the mating season begins, as individuals begin mate searching for widely spaced, sedentary females (Duvall *et al.,* 1993; Duvall and Schuett, 1997; Cardwell, 2008; Anderson, 2010; Glaudas and Rodríguez-Robles, 2011; Putman *et al.,* 2013). This pattern is also supported by patterns observed in other telemetry projects done in tropical Asia (Barnes *et al.,* 2017; Devan-Song *et al.,* 2016; Marshall *et al.,* 2019).

II)   Home Range Estimates

There was a statistically significant increase in activity range polygons (95% and 99%) for all snakes between the monsoon and post-monsoon seasons. However, the core ranges (50%) of translocated snakes were less than those of control snakes in the post-monsoon period (Figure 13).

The increase in activity range but not in core range coincides with the patterns observed in movement variables. Since the breeding season occurs in the post-monsoon months, the decrease in core range in translocated snakes combined with the lack of mating observations suggests that translocation may interfere with their behaviour ecology. Control males that were found with a female spent several days paired before recommencing movement, likely increasing their core range. Again, no statistically significant differences between pre-monsoon and monsoon movement were found, regardless of group.

Environmental Variables

No significant relationship between rainfall and movement was found. However, there was a significant increase in movement as temperatures increased. Environmental factors are well-documented to influence snake ecology in temperate zones. In temperate regions, temperatures vary widely, as such, thermoregulation plays a vital role in space-use and life history (King & Duvall, 1990; Eskew and Todd, 2017). This difference is reflected in the seasonal movement patterns of telemetered snakes in temperate regions (Reinert and Rupert, 1991; Nowak *et al.,* 2002). However, in tropical regions, temperature shifts are less drastic and less significant in the ecology of snakes (Brown and Shine, 2002). However, temperature and rainfall were both collected at The Gerry Martin Project as opposed to at the location of each snake, as weather can be very variable across the study site, it is possible that the true relationship between movement and temperature/rainfall is masked.

Different environmental variables may also offer greater influence on movement patterns. For example, surface temperature and humidity may play a more significant effect in the movement of individual snakes due to the influence of differing microclimates in varying plantations. For example, banana and palm plantations are likely to offer more vegetation cover and increased humidity due to the presence of a canopy, compared to more open plantations e.g., ginger and bean plantations. Mixed crop plantations will also offer unique microhabitats.

Further Work

Although some patterns were elucidated in this study, there is scope for further work. An increased sample size would improve the statistical robustness of similar studies. Long-term effects are difficult to predict due to the limited time period in which the study snakes were tracked. Tracking over several years would allow this. Further work on environmental, microhabitat, macrohabitat and behavioural ecology variables may elucidate additional differences between resident and translocated snakes.

Inclusion of translocated females in future studies would also be of great value. Female snakes undergo different selection pressures to males. This is

documented in many viper movement studies. Female vipers typically move smaller distances than males, this is especially pronounced in the breeding season where males move more whilst mate searching (Duvall *et al.,* 1993; Duvall and Schuett, 1997; Cardwell, 2008; Anderson, 2010; Glaudas and Rodríguez-Robles, 2011; Putman *et al.,* 2013). It is also pronounced in the dry season when females are gravid, during which time they spend protracted periods of time in underground burrows as their locomotory capacity is inhibited (Seigel *et al.,* 1987). This is also reflected in preliminary work on the spatial ecology of the control snakes tracked at The Gerry Martin Project (Kuttalam, 2020). Given that translocated males were not observed partaking in mating behaviour, it is possible that translocated females would be similarly affected during the mating season. If so, they may display different movement ecology to resident females.

One female *D. russelii* was translocated during the study. Formerly a member of the control population, it was translocated over a short distance due to conflict with a landowner. T5/TR1 demonstrated the same behaviour as resident females staying in underground burrows for several weeks during the dry season and giving birth in May. However, as a former member of the resident population, TR1 was translocated over a short distance, within its potential home range and a such was likely released into a receptor site that was very similar to its original range. It is well documented that snakes that undergo short distance translocation display fewer effects to both movement patterns and behavioural ecology (Hardy *et al.,* 2001; Brown *et al.,* 2009; Sullivan *et al.,* 2014).

A greater understanding of the effects of seasonality would be achieved if translocated snakes were tracked for the full year. Currently, it is not possible to compare the movement ecology of resident and translocated snakes during the dry season, as translocated snakes were not tracked during this period. This would be particularly valuable to compare the effects of translocation on female gestation.

Morphometric data would be extremely valuable to assess the effects of translocation on the body condition of *D. russelii*. As aforementioned, two of the translocated snakes displayed severe decline in body condition which ultimately led to their mortality. Longevity data would also be an effective metric of

translocation success. During the study period (April to November) of 11 total translocated snakes tracked, 7 died of either predation, human interference, or poor health (Appendix A). During the same period, of 7 control snakes, two died of predation and human interference respectively. However, 4 of the control snakes (T1-4) used in the study were already being tracked in the field prior to the commencement of the study. For example, T1 had been tracked from October the previous year and was still in the field post the completion of this study. Unlike the translocated snakes where none of the snakes were remaining in the field at the end of the study period, three of the control snakes remained. Two control snakes and three translocated snakes were lost during the study, this is assumed to be the result of transmitter failure. Unfortunately, in this study logistical problems led to the loss of morphometric data and the date of some individuals' death. Despite this, there is sufficient topical data to suggest that the longevity and body condition of *D. russelii* are likely negatively impacted by long-distance translocation treatment, mirroring many translocation studies (Dodd and Seigel, 1991; Reinert and Rupert, 1999; Plummer and Mills, 2000; Nowak *et al*., 2002; Butler *et al*., 2005a,b; Barve *et al,* 2013; Sullivan *et al.,* 2014).

Additional research on the effect of translocation on human-snake conflict at the receiver site would be impactful. Although this study has gone some way in addressing this by assessing the movement ecology of both groups, it does not address the possible impacts of translocation on the behavioural ecology of translocated snakes. For example, a risk assessment of snakes' respective proximity and accessibility to human activity e.g. manual work and foot traffic would offer an insight into the respective risk of snakebite to humans between control and translocated groups. Although, translocated snakes do not display aberrant movement patterns which could cause increased conflict, it is possible that increased conflict could occur due to aberrant behaviour. As translocation is likely to remain a popular tool, it would be invaluable to gain a greater understanding of the effect on human-snake conflict at translocation sites (Barve *et al.,* 2013; Sullivan *et al.,* 2014).

Impact

If translocation is shown to have no effect on movement patterns in Russell's vipers, this would have major implications for snake-bite prevention. This is especially relevant in India, where large numbers of these snakes are translocated on an annual basis (Barve *et al.*, 2013).

However, if the limited survivorship data is reflected in more extensive studies there is a concern that translocation leads to decreased survivorship and as such calls into question the efficacy of translocation methods. Likewise, for the decrease in body condition and possible impacts on behavioural ecology. Few studies have examined the sub-lethal effects of LDT such as effects on behaviour and negative impacts on physiology (Heiken *et al.,* 2016). This study highlights the importance of answering these questions.

The combination of increased movement patterns, motion variance and home ranges in the post-monsoon confirm that the transition from the monsoon to the post-monsoon is important in the movement ecology of Russell's Viper. Further research is needed to determine whether these observations are due to climatic changes and the commencement of the mating season.

Conflict of Interest

I declare no conflict of interest.

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Appendices

A) Longevity Data

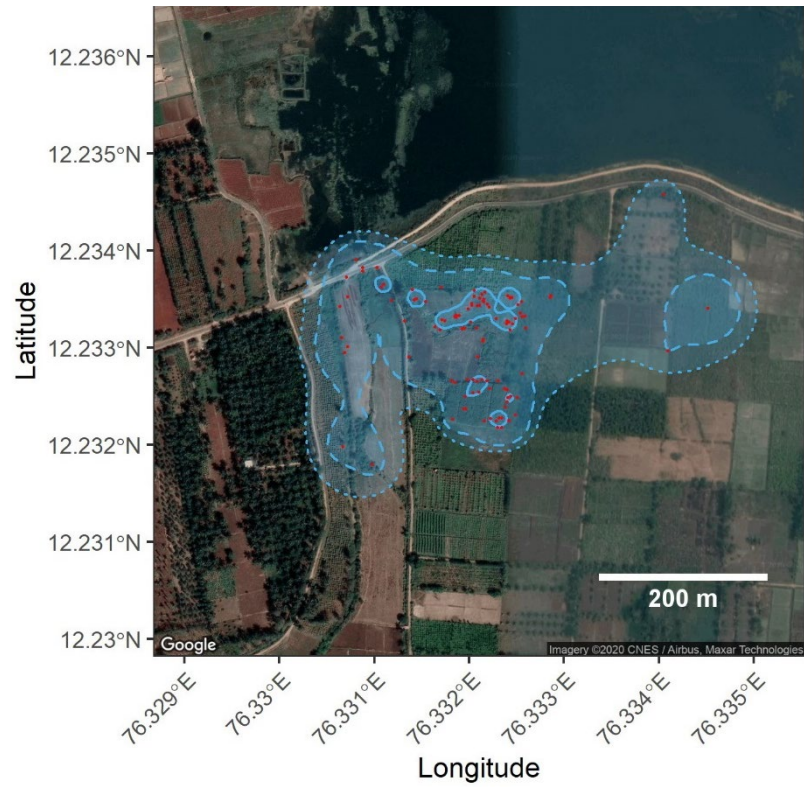| ID	Tracking Period	Fate
T1	16/10/2019 - Present	N/A
T4	22/09/2019 - 01/02/2020	Signal lost
T7	25/12/2018 – 10/10/2018	Killed, hit on head.
T8	29/12/2018 - Present	N/A
T12	04/05/2019 - Present	N/A
T15	18/05/2019 – 03/07/2019	Found transmitter, likely predation.
T18	02/06/2019 – 07/02/2020	Signal lost.
TR2	13/04/2019 – 24/04/2019	Killed, found burnt.
TR3	13/04/2019 – 12/06/2019	Found transmitter, likely predation.
TR4	23/04/2019 – 12/08/2019	Found transmitter, likely predation.
TR5	02/05/2019 – N/A	Killed, found burnt. In poor body condition at the time.
TR6	02/05/2019 – N/A	Taken into captivity.
TR7	04/09/2019 – 15/11/2019	Signal lost, likely transmitter failure.
TR8	09/09/2019 – 22/11/2019	Died of poor health.
TR9	17/09/2019 – 08/10/2019	Signal lost, likely transmitter failure.
TR10	04/10/2019 – N/A	Signal lost, likely transmitter failure.
TR11	26/10/2019 – N/A	Cause of death unclear.
TR12	26/10/2019 – N/A	Killed, mangled by rotovator, and burnt.

B) Analysis Data

I) Data Summary

Group	Time	No. of Specimens	No. of Data Points	Average Daily Movement (m)	Mean Distance per Movement (m)	Movement Frequency (%)	Motion Variance	dBBMM Polygons (ha)		
								50%	95%	99%
Control	Full Year	7	1024	19.39±2.00	41.60±2.55	45.62	0.32±0.08	0.27±0.08	4.48±1.30	9.70±3.28
	Pre-Monsoon	5	219	22.98±0.60	35.26±1.36	64.21	0.39±0.05	0.20±0.04	1.82±0.31	2.77±0.45
	Monsoon	7	599	12.36±2.09	29.21±2.78	41.07	0.14±0.05	0.13±0.03	1.82±0.63	3.01±1.07
	Post-Monsoon	5	180	43.93±6.57	104.51±15.60	43.04	1.47±0.45	0.71±0.29	8.08±3.67	12.76±5.58
Translocated	Full Year	7	724	17.51±2.54	60.84±9.39	29.29	0.58±0.17	0.14±0.04	3.44±1.32	8.16±3.57
	Pre-Monsoon	4	156	22.15±5.05	54.31±11.94	39.33	0.62±0.20	0.15±0.07	1.77±0.57	2.86±0.79
	Monsoon	5	329	14.80±3.12	45.78±6.06	31.37	0.37±0.10	0.12±0.04	1.3±0.37	2.54±0.59
	Post-Monsoon	5	236	24.92±7.17	96.08±21.53	24.93	1.49±0.73	0.04±0.01	6.37±3.28	12.56±6.12

II) Statistical Summary

| Test	Variable	Control	Translocated
Spearman's Correlation	Rainfall	$r_s = -0.063$, N =218, $P = 0.353$	$r_s = -0.073$, N =218, P = 0.284
	Movement After Rainfall	$r_s = 0.039$, N =128, $P = 0.661$	$r_s = 0.052$, N =128, $P = 0.557$
	Temperature	$r_s = 0.281$, N = 192, $P< 0.001$	$r_s = 0.342$, N = 192, $P< 0.001$
Kruskal-Wallis	Mean Distance per Movement	$P< 0.001$	$P< 0.001$
Two-Way ANOVA	Average Daily Movement	$F_{(2,25)} = 2.034$, $P = 0.152$	
	Movement Frequency	$F_{(2,25)} = 1.914$, $P = 0.169$	
	Brownian Motion Variance	$F_{(2,25)} = 1.390$, $P = 0.587$	
	50% dBBMM Polygon	$F_{(2,25)} = 4.258$, $P = 0.026$	
	95% dBBMM Polygon	$F_{(2,25)} = 0.116$, $P = 0.891$	
	99%dBBMM Polygon	$F_{(2,25)} = 0.148$, $P = 0.863$	
Independent Samples t-test	Average Daily Movement	$t_{12} = 0.562$, $P = 0.585$; diff. = 1.804, 95% C.I. = -5.191 to 8.799	
	Movement Frequency	$t_{12} = 3.856$, $P = 0.002$; diff. = 16.331, 95% C.I. = 7.104 to 25.557	
	50% dBBMM Polygon	$t_{12} = 1.506$, $P = 0.158$; diff. = 0.13, 95% C.I. = -0.058 to 0.318	
	95% dBBMM Polygon	$t_{12} = 0.560$, $P = 0.586$; diff. = 1.307, 95% C.I. = -2.999 to 5.073	
	99%dBBMM Polygon	$t_{12} = 0.319$, $P = 0.756$; diff. = 1.543, 95% C.I. = -9.016 to 12.101	
Welch's Independent Samples t-test	Mean Distance per Movement	$t_{6.881} = -1.979$, $P = 0.089$; diff. = -19.246, 95% C.I. = -42.327 to 3.836	
	Brownian Motion Variance	$t_{8.264}= -1.378$, $P = 0.204$; diff. = -0.261, 95% C.I. = -0.695 to 0.173	

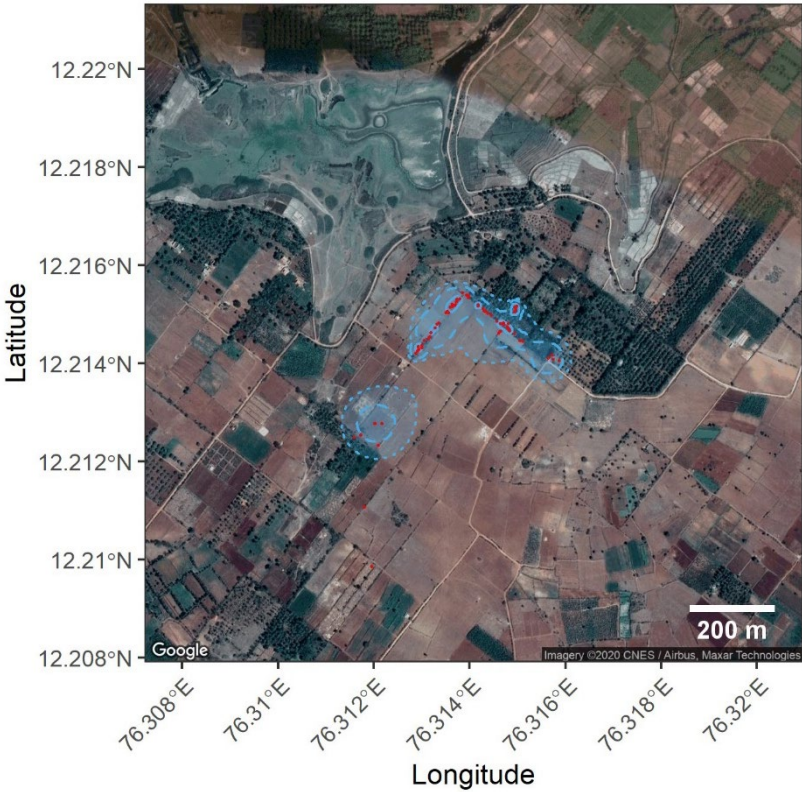## C) Motion Variance

TR3

TR4

TR5

TR6

TR7

TR8

TR10
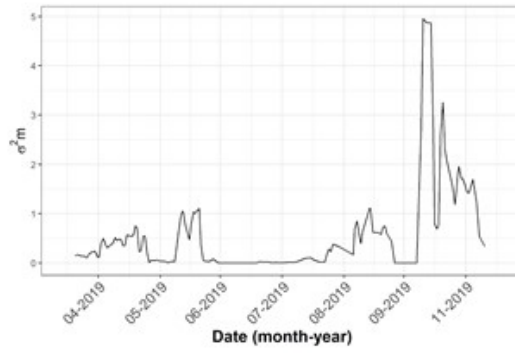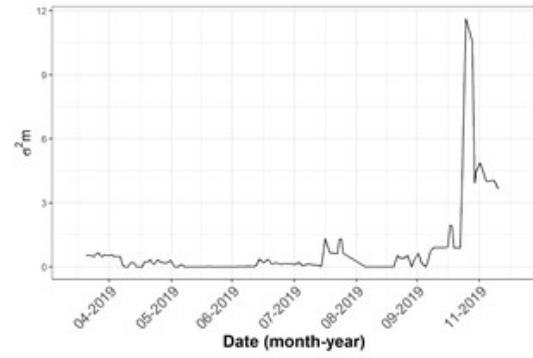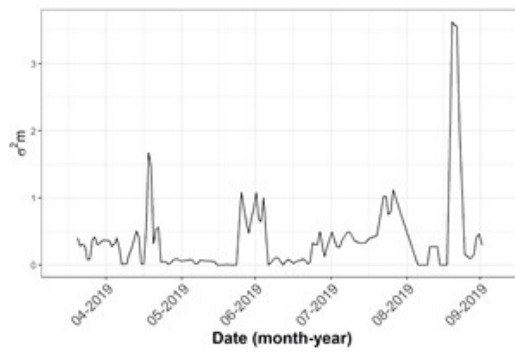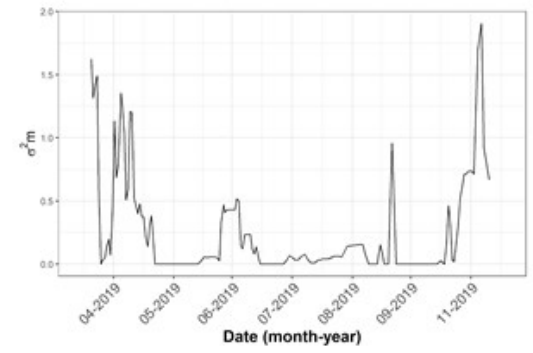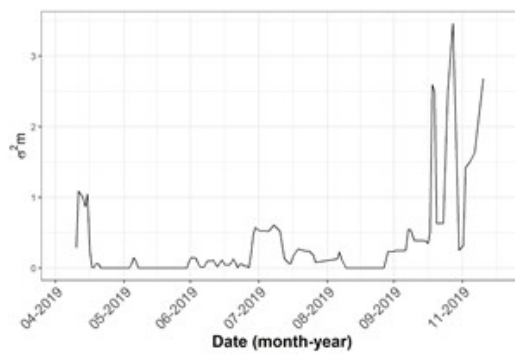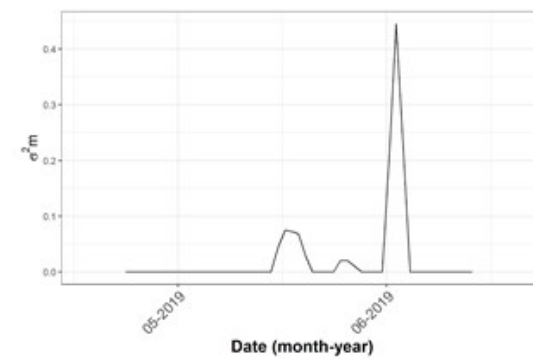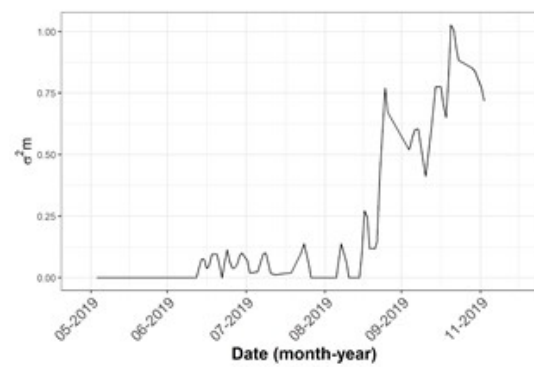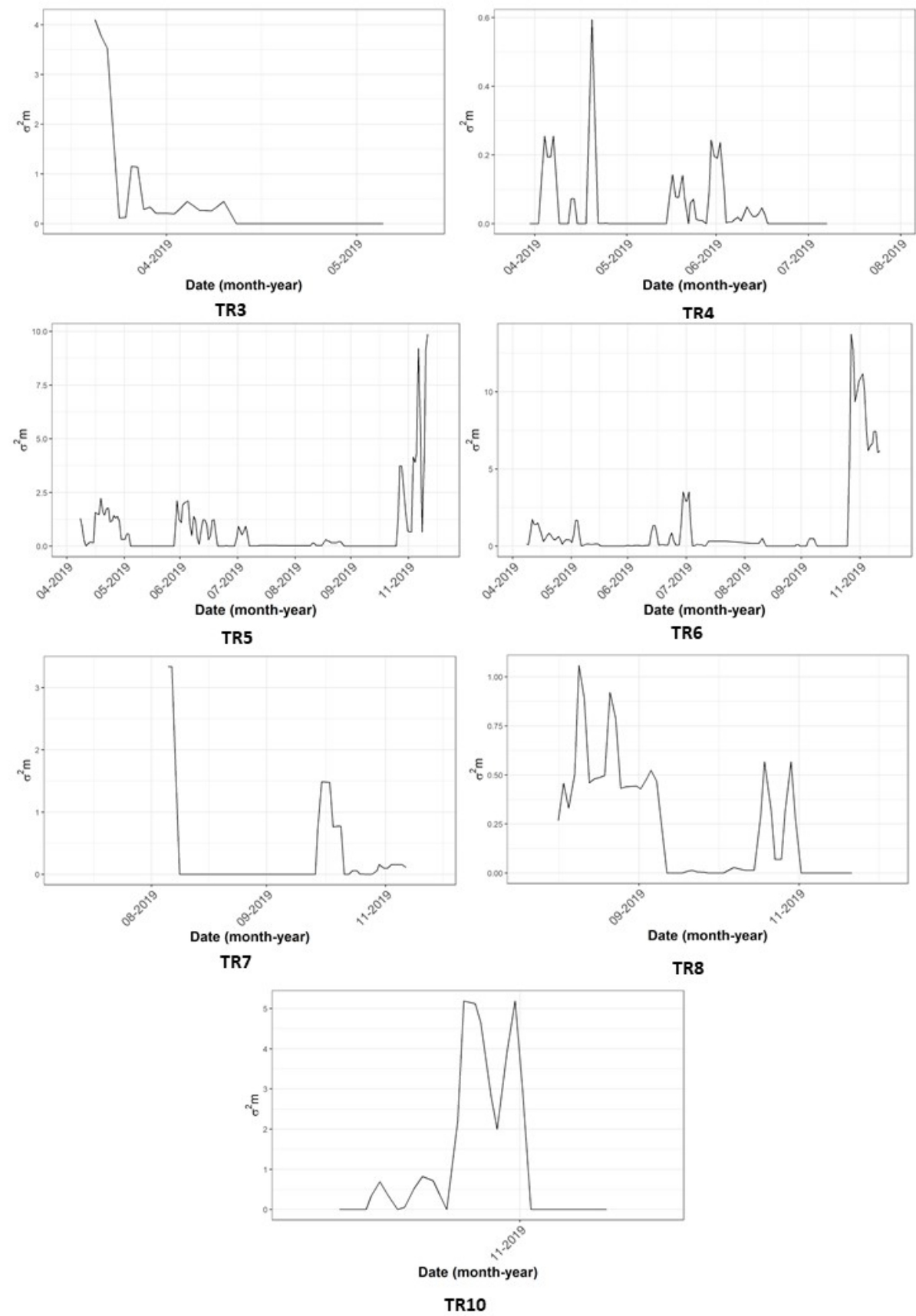
D) Home Range Maps – Full Term

T1

T4

T7

T8

T12

T15

T18

TR3

TR4

TR5

TR6

TR7

TR8

TR10
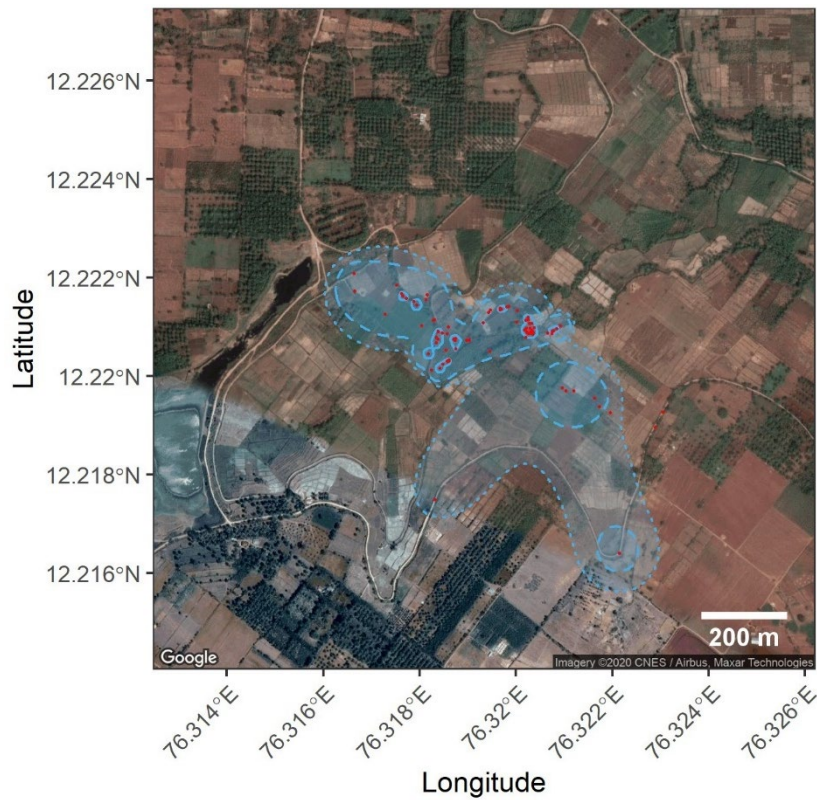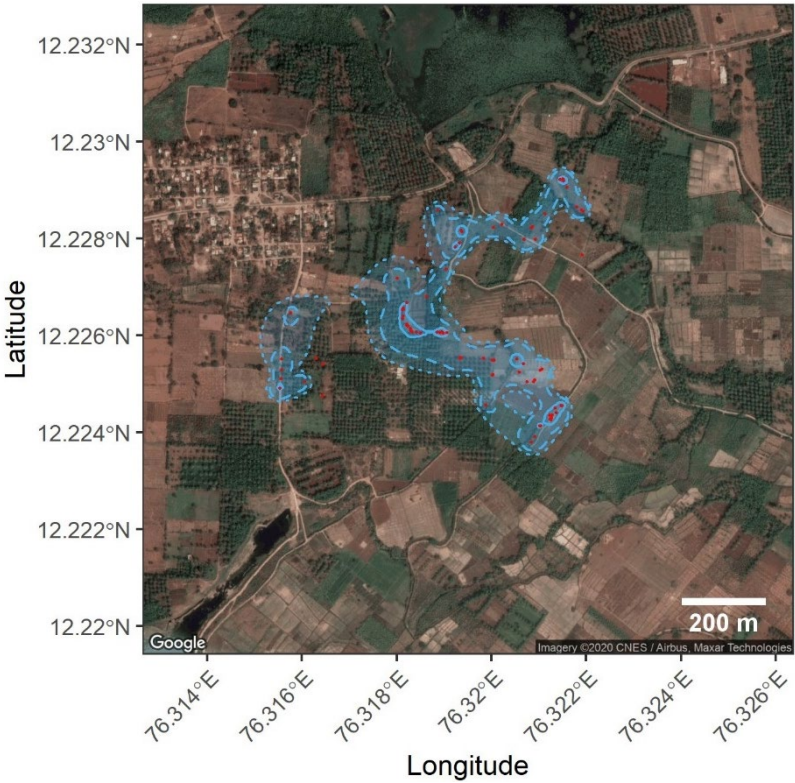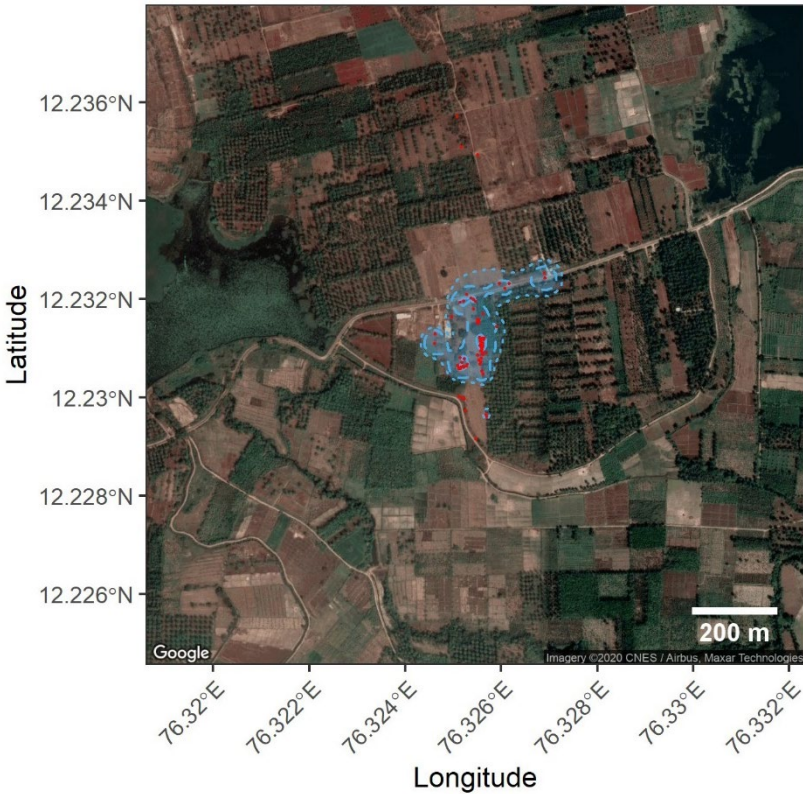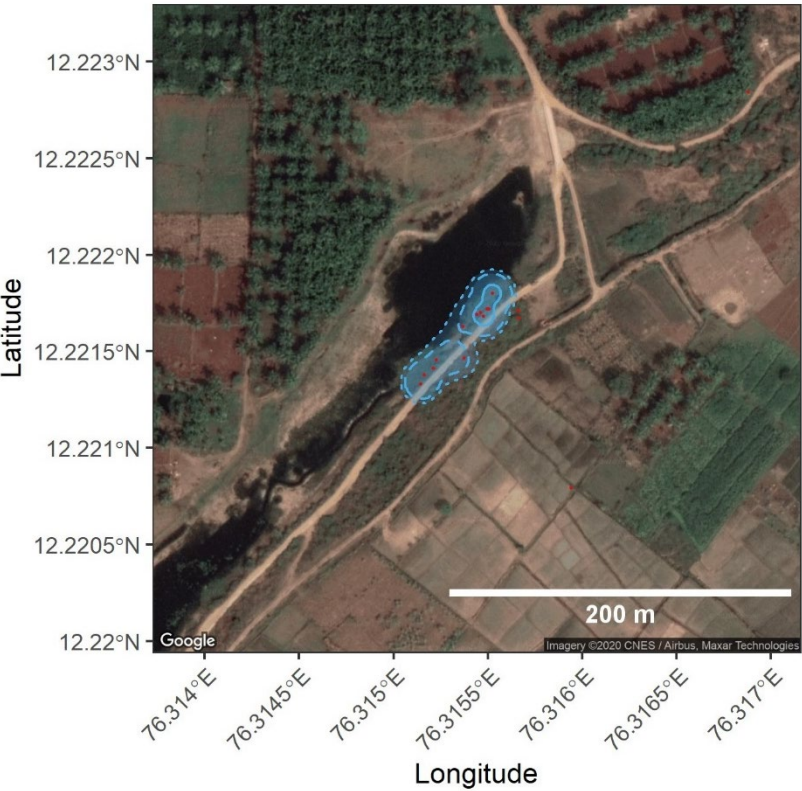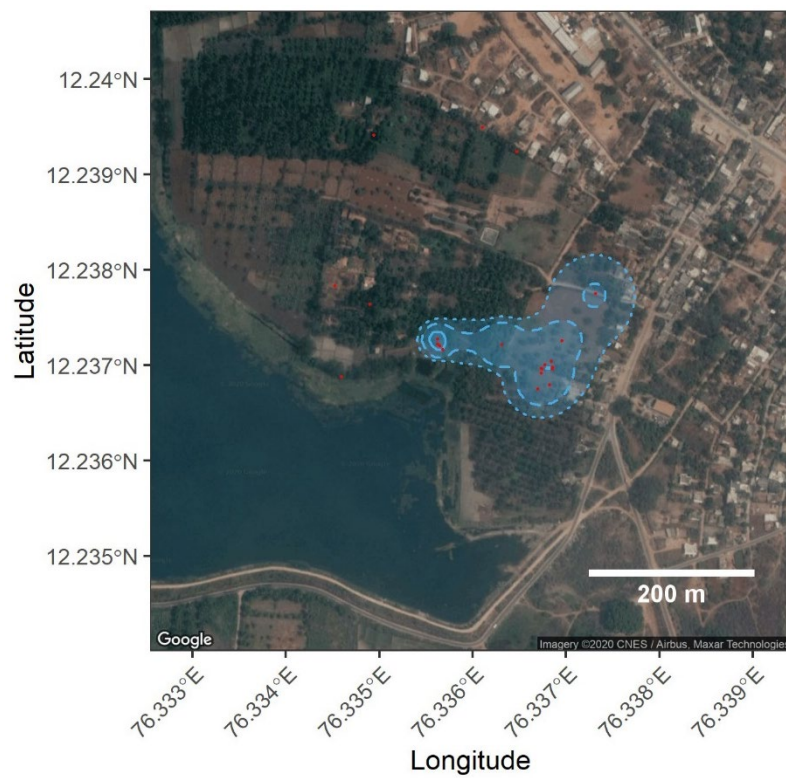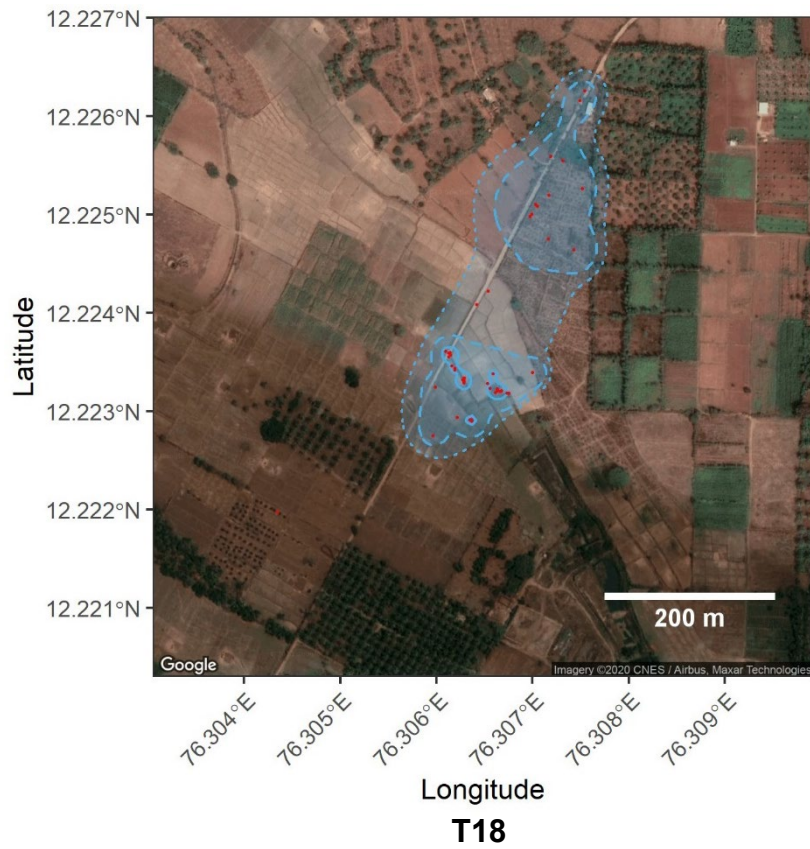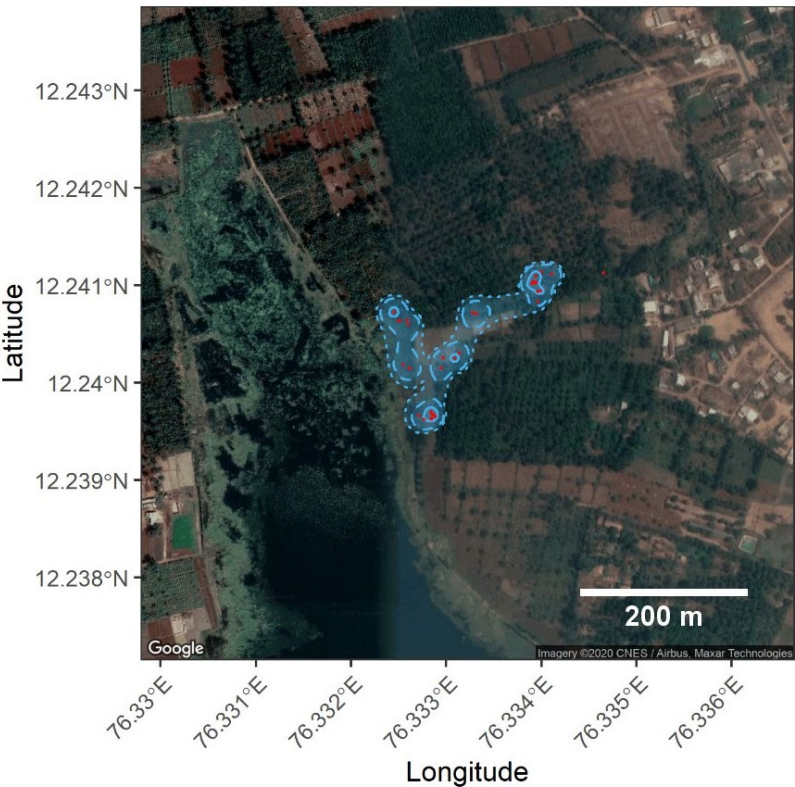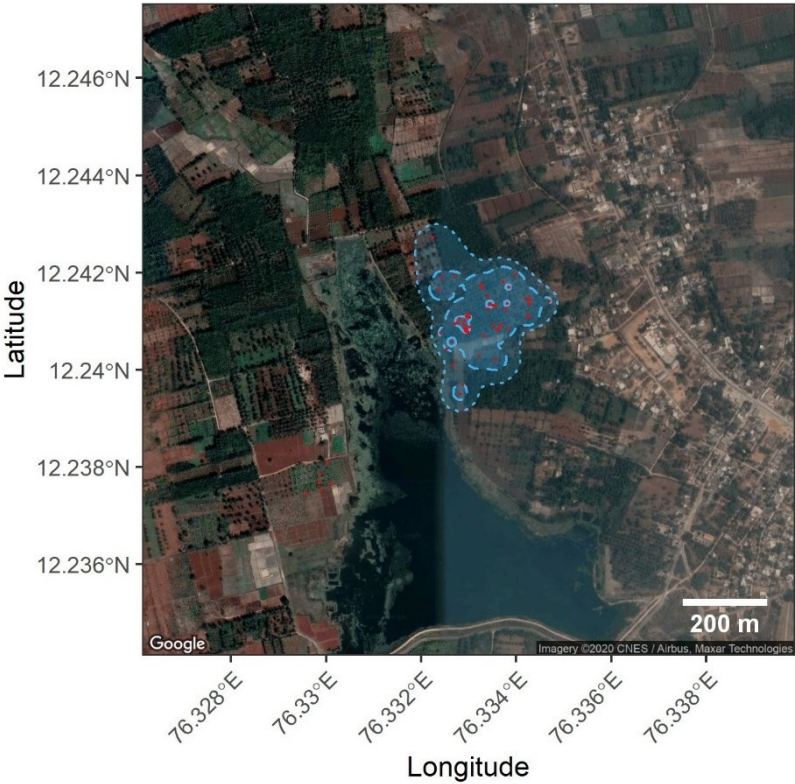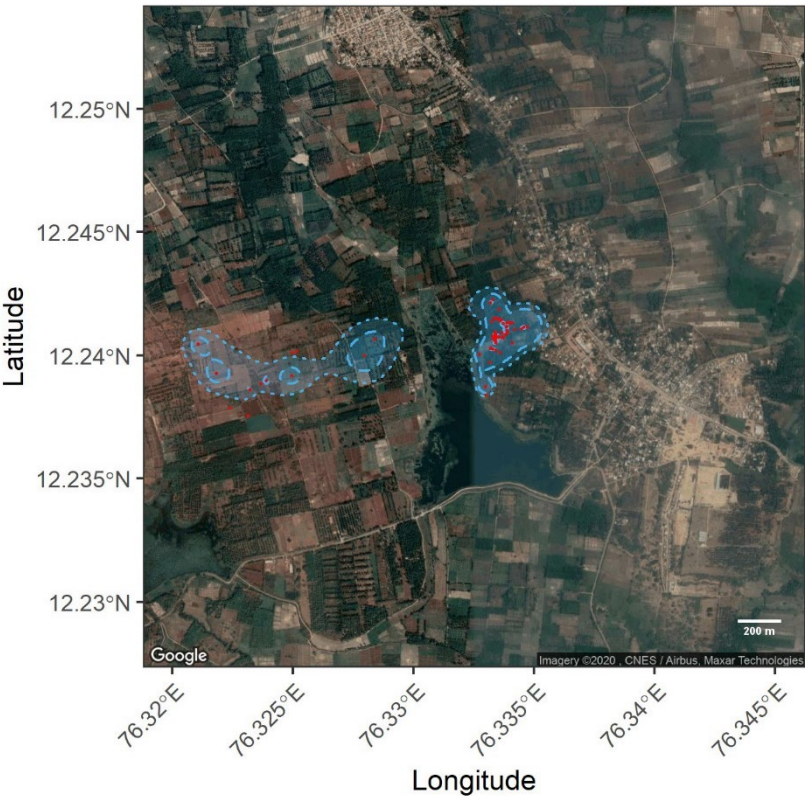
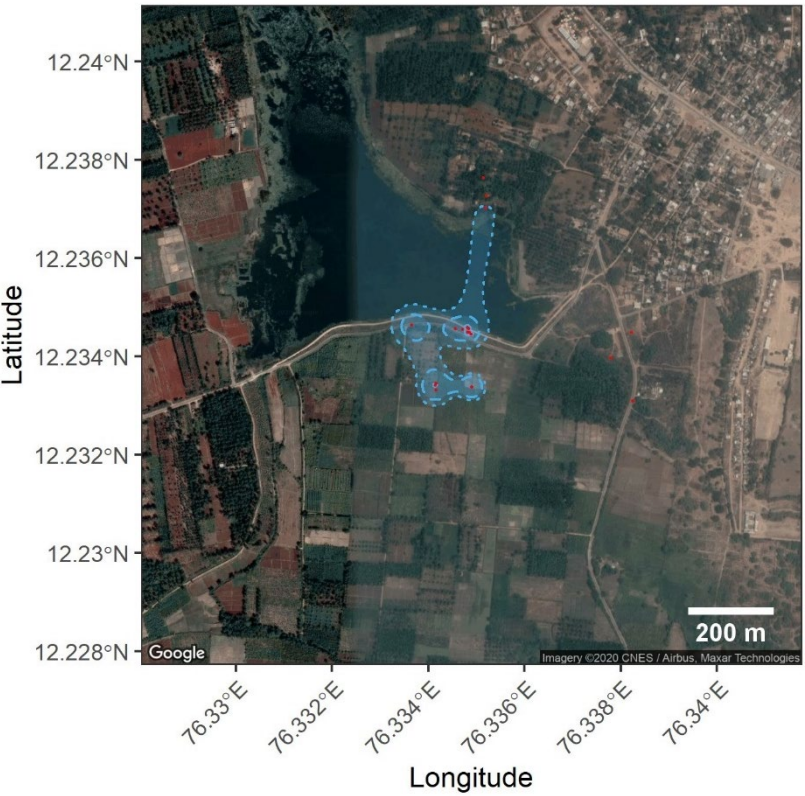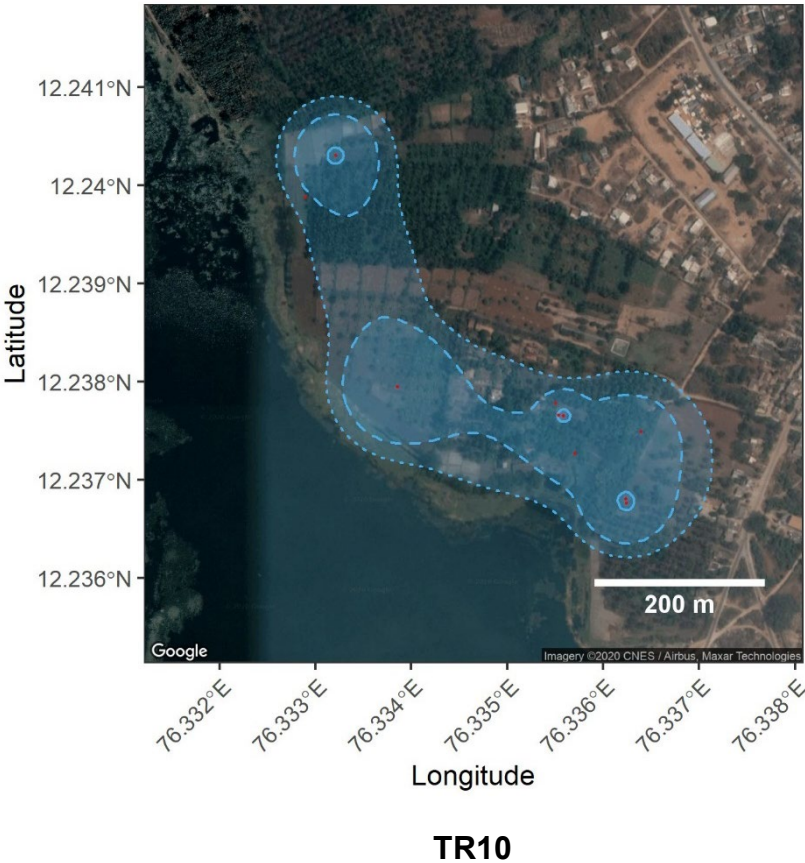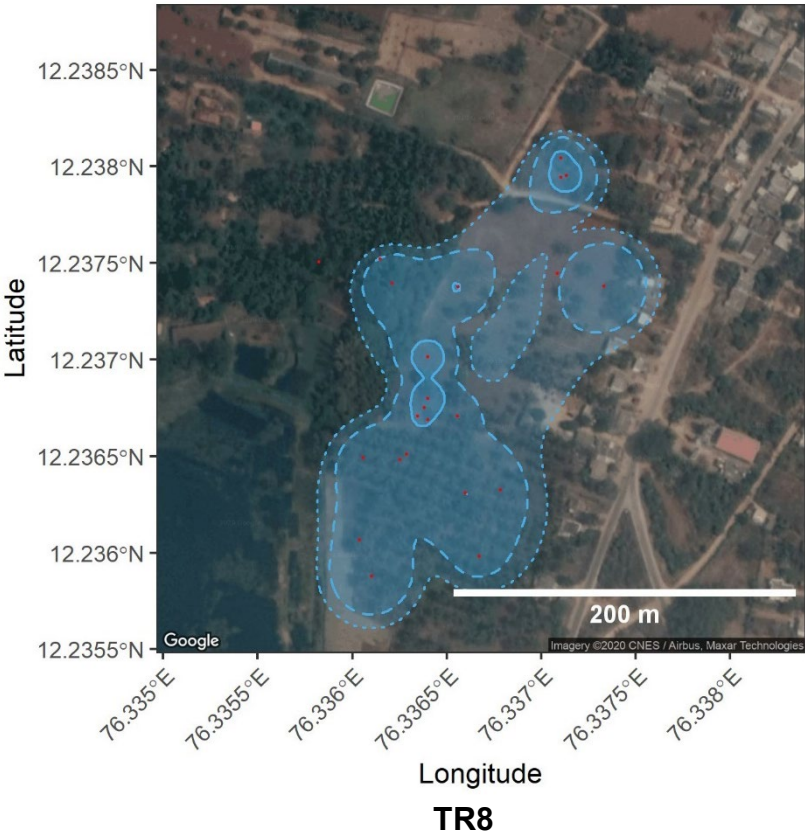**<u>Supplementary Material</u>**

RScript

Open progrmmes.

> library(ggplot2) # creating graphics

> library(scales) # Manipulate dats

> library(dplyr) # data management

> library(move) # movement functionality, dBBMMs

> library(adehabitatHR) # home range package, utilization dist.

> library(ggspatial) # plotting ranges in ggplot

> library(rgeos) # calculating area

> library(stringr)

> library(ggmap)

**## Set
Directory**
setwd("")

Read File
fdry <-
read.csv("")

Date & time for models.

> datetime <- as.POSIXct(x = paste(fdry$Date, fdry$Time),
format = "%d/%m/%Y %H:%M")

dplyr & select funtion to pull columns from the data.

> names(fdry) >
fdry <- fdry %>%

```
dplyr::select("ID"
,
            "Easting", "Northing")
```

Add datetime column to the dataframe.

```
> fdry$datetime=datetime
```

Rename columns for ease of use.

```
> names(fdry) <- c("animal", "x", "y", "datetime")
```

Define date and time.

```
> fdry$datetime <- as.POSIXct(fdry$datetime,
format = "%Y-%m-%d %H:%M:%S",
tz = "Asia/India")
> summary(fdry)
```

Display tracking durations and gaps between points.

```
> ggplot(fdry) +   geom_point(aes(x =
datetime, y = animal))
```

Plot UTMs to identify outliers or incorrect co-ordinates.

```
> ggplot(fdry) +   geom_point(aes(x = x, y = y,
colour = animal)) +   scale_colour_viridis_d() +
coord_equal()
```

Density plot to track lag time.

```
> fdry %>%   group_by(animal) %>%   mutate(time.lag =
as.numeric(difftime(datetime, lag(datetime), units = "hours")))
%>%
```

```
  ggplot() +   geom_density(aes(x = time.lag, group = animal), fill = "black",
alpha = 0.25) +   scale_x_log10()
NULL
```

Filter data using dplyr to select the snake to model. E.g. T15

```
> T15 <- fdry %>%
filter(animal == "T15")
> set_loc.error <- 5
> move.obj <- move(x = T15$x, y = T15$y, proj = CRS("+init=epsg:32647"),
          time = T15$datetime)
>move.obj
```

Set window size and margin. Margin must be smaller than window.

Model has a window size of 15 and margin of 7.

```
> ws <- 15
> mrg <- 7
> set_grid.ext <- 5
> set_dimsize <- 1000
```

Run dBBMMs.

Pull current start time.

```
> ind.start <- Sys.time()
> dbbmm <- brownian.bridge.dyn(object = move.obj,
            location.error =
set_loc.error,                    margin =
mrg,                 window.size = ws,
ext = set_grid.ext,
dimSize = set_dimsize,
verbose = FALSE)
```

```
> print(paste("------ dBBMM computation time:",

       round(difftime(Sys.time(), ind.start, units = "min"), 3), "mins"))

>dbbmm
```

Calculate motion variance.

```
>T15$var <- getMotionVariance(dbbmm)

> T15
```

Plot data and assess variance over time.

```
> var.plot <- ggplot(T15) +
geom_line(aes(x = datetime, y = var)) +
theme_bw() +
  scale_size_manual(values = 0.6) +
scale_x_datetime(labels = date_format("%m-%Y"),
breaks = date_breaks("month")) +   labs(x = "Date (month-
year)", y = (expression(paste(sigma^2,"m")))) +
theme(axis.text.x = element_text(size = 14, angle = 45,
hjust = 1),        axis.title.y = element_text(size = 14),
axis.title = element_text(size = 16, face = 2))
> var.plot

> ggsave(filename = paste0(T15$animal[1],
"_MoveVarplot.png"),        plot = var.plot,        dpi = 300,
height = 12,        width = 18,        units = "cm")
```

Generate map without existing satellite image.

CRS for the maps for given location, in this case, Karnataka.

```
> utm <- CRS("+proj=utm +zone=43 +datum=WGS84 +units=m +no_defs")

> coords <- cbind(T15$x, T15$y)

> SP <- SpatialPoints(coords,proj4string = utm)
dbbmm.sp <- as(dbbmm, "SpatialPixelsDataFrame")
dbbmm.sp.ud <- new("estUD", dbbmm.sp)
```

@ is

```
dbbmm.sp.ud@vol = FALSE

dbbmm.sp.ud@h$meth = "dBBMM"

dbbmm.ud <- getvolumeUD(dbbmm.sp.ud, standardize = TRUE)

> plot(dbbmm.ud)

> poly.050 <- getverticeshr(dbbmm.ud, percent = 50)

> poly.095 <- getverticeshr(dbbmm.ud, percent = 95)

> poly.099 <- getverticeshr(dbbmm.ud, percent = 99)
```

Convert to lat-long. Works best with ggmap.

```
> latlong <- CRS("+init=epsg:4326")

> SPlatlong <- spTransform(SP, latlong)

> poly50 <- spTransform(poly.050, latlong)
> poly95<- spTransform(poly.095, latlong)
> poly99 <- spTransform(poly.099, latlong)
```

Pass location to ggmap to centre the map on the points.

Generate mean of both x and y axis to keep as a numeric vector.

```
> location <- c(mean(SPlatlong@coords[,1]), mean(SPlatlong@coords[,2]))

> dBBMM.plot <- ggplot() +   geom_spatial_polygon(data = poly.050, aes(x
= long, y = lat, group = group), alpha = 0.15, crs = 7780) +
  # each polygon is a contour
geom_spatial_polygon(data = poly.095, aes(x = long, y = lat, group =
group),                    alpha = 0.15, crs = 7780) +
geom_spatial_polygon(data = poly.099, aes(x = long, y = lat, group =
group),                    alpha = 0.15, crs = 7780) +
coord_sf(crs = 7780) +   geom_point(data = T15, aes(x = x, y = y), alpha =
0.25, size = 0.5) +   labs(title = T15$animal[1], x = "Longitude", y =
"Latitude") +   theme_bw() + theme(legend.position = "bottom", axis.text.x
element_text(angle = 45, hjust = 1))
```

>dBBMM.plot

```
> ggsave(filename = paste0(T15$animal[1],
"_dBBMMplot.png"),     plot = dBBMM.plot, dpi = 300, height =
12, width = 18, units = "cm")
```

Generate a satellite map

Use API key from google to input into the below function

> https://cloud.google.com/maps-platform/register_google(key = "")

Adjust zoom levels for best map.

```
> map <- get_map(location = location, crop = F,
         maptype = "satellite",
source = "google", zoom = 15)
```

```
>dbmap <- ggmap(map) +

  geom_polygon(data = poly50, aes(x = long, y = lat, group = group), alpha = 0.2, fill
= "#49ace5", linetype = 1, colour = "#49ace5") +

  geom_polygon(data = poly95, aes(x = long, y = lat, group = group),alpha = 0.2, fill
= "#49ace5", linetype = 2, colour = "#49ace5") +

  geom_polygon(data = poly99, aes(x = long, y = lat, group = group), alpha = 0.2, fill
= "#49ace5", linetype = 3, colour = "#49ace5") +

  geom_point(data = data.frame(SPlatlong@coords), aes(x = coords.x1, y =
coords.x2), colour = "red", pch = 16, size = 0.2) +

  coord_sf(crs = 4326) +

  geom_point(data = TR4, aes(x = 94, y = 0), alpha = 0.5, colour = "red", pch = 16,
size = 0.2) +

  labs(title = TR4$animal[1], x = "Longitude", y = "Latitude") +

  theme_bw() +

  theme(legend.position = "bottom",
      axis.text.x = element_text(angle = 45, hjust = 1))
```

Function in ggmap/ggplot to produce and format scalebars appropriately.

```
> scalebar(data = "T15", location = "bottomright", dist = 10,

  dist_unit = "m", transform = "TRUE", dd2km = NULL, model = "WGS84",

  height = 0.02, st.dist = 0.02, st.bottom = TRUE, st.size = 5,

  st.color = "white", box.fill = c("black", "white"),

  box.color = "black", border.size = 1, x.min = NULL, x.max = NULL,

  y.min = NULL, y.max = NULL, anchor = NULL, facet.var = NULL,

  facet.lev = NULL, ...)
```

Generate dBBMM home range estimates.

```
> gArea(poly.099) / 10000

> gArea(poly.050) / 10000

>gArea(poly.095) / 10000
```

Generate citations.

```
> citation()

> citation("ggplot2")

> citation("scales")
> citation("dplyr")

> citation("move")

> citation("adehabitatHR")

> citation("ggspatial")

> citation("rgeos")
```