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Herping the Himalayas; In search of Rare Cobras and Western Toilets

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This field report will focus on the expedition which Captive & Field Herpetology (C&FH) ran to the Himalayan regions of Himachal Pradesh in 2019. It'll jump in and out of a previous 2018 expedition now and then, primarily to fill in the gaps where we were unsuccessful in 2019. Due to some illnesses I didn't carry out a great job of noting dates when taking notes so this report won't follow the normal day by day or week by week structure of a field report, it'll use more of a case by case structure.

In 2018, we ran our first ever Himalayan expedition, it was and still sits high up on my list of most successful field excursions. Part of a large collaboration focussing on snakebite awareness from the ground up (the people most at risk) and educating various forest departments in the state, we had a successful trip from all angles. We handed out huge numbers of snakebite awareness materials to schools and local groups, we carried out numerous forest department training sessions teaching them about snake biology, handling and what to do when a person is confronted by a venomous snake. We also located new species for the state, range extensions and ticked off most of, if not all of our target species. One of those species, especially for myself and a couple of other members in the group was the Caspian cobra, *Naja oxiana* (figure 1). A couple of weeks in, we were greeted by this majestic high-altitude snake whilst taking a break from road cruising at above 2000m altitude. Anyone who has had the pleasure of finding cobras in the wild will certainly be shocked to know that we found this individual at this altitude and an air temperature of 8c, it was foggy and damp with very little to no warmth coming off the concrete road. That would be it until the last few days of the trip when we unfortunately came across a second specimen, minutes after it had been run over by a car. Its heart was still beating when we found it. That specimen now resides in the Zoologial Society of India's collection and is the first of its species to enter the collection. So that's enough of 2018 for now, hopefully you can understand why we were excited to get back there in 2019…

The 2019 expedition started off as expected. The first couple of weeks involved some forest department training with some close friends, Ana and Stu who were conducting the training and surveys with Vishal as part of funding which Bangor University had received. We'd often and still do maintain some friendly competition when it comes to herping and the first night that we managed to get on the road in Solan was no exception. The previous year, Stu was first to spot a snake during the trip, not too far away from the location which we were currently road cruising. For anybody that doesn't know what road cruising it, it involves driving up and down roads at night at a slow pace looking for snakes as they either cross them or come out to bask on the 'charged up' tarmac, warmed up from the days sun. It was a slow night, slamming the brakes on for numerous objects such as sticks, anybody who has road cruised will understand the pain of this. Stu had mentioned that he would, again, find a green pit-viper, *Trimeresurus septentrionalis* during this evening's cruise, just like the previous year (figure 2)…

Figure 1. The Caspian cobra, *Naja oxiana*. Situated in one of the most abundant plants in Himachal Pradesh, Marijuana. This was the first and only live specimen we found in 2018.

It was a long night, we experienced some heavy showers and very few herps. We stopped at some of the locations from the previous year. They presented us with the usual suspects; Asian toads and geckos of the genus *Hemidactylus*. It was on the drive back, maybe about 20 minutes from our accommodation, just as we were all drifting in and out of sleep that I heard those golden words being shouted from the top of Stu's lungs "SNAKE!". All of us, including Vipin, the driver, being half asleep resulted in the car coming to a stop at a not so optimal location and we ultimately had to reverse back about 50 meters. It was a great spot, about 15 meters up off the road on quite a thickly vegetated bank. Often, when you find snakes at night, you're presented with a bright, scaly and reflective object, like a bundle of metal sleeping on a branch. When you find green pit-viper, you are presented with, well, the green equivalent. There's no mistaking one and that's what we had here. Who would've guessed it?! Green pit-vipers can be weirdly common in some locations, whilst not 'rare' in Himachal Pradesh, we're certainly never tripping over them.

So the race was on, only about 20 minutes of drive time left and I needed a snake. My hopes were low. It only took about 2 minutes for everyone to start drifting off to sleep again and I didn't really have much expectation of finding another snake. I was sat in the back seat, with the window open and torch beaming the banks of the road. I was doing my best to scan, with my half open eyes. We weren't really driving at a slow/road cruising kind of pace any more. Vipin was likely exhausted and ready to crash (into his bed, not the car, although I do question this sometimes with the speeds he opts to drive at). Then, I noticed a flash of black and white a couple of meters above the road on what could be best described as a mud wall. It looked as if it was crawling in between the many small trees growing out of this 'mud wall'. Expecting to see a reflective branch or maybe, if we were lucky, a wolf snake (*Lycodon sp*.), I yelled "snake!". We went through the phases of finding something during a road cruise; slam brakes on, damage everyone's ribs/shoulders (heads if not wearing belts); run out of car whilst forgetting all handling and capture equipment; either find snake or massively frustrating snake like object. We were not greeted by a wolf snake but a rather large common krait (*Bungarus caeruleus*) (figure 3). This was probably the largest common krait I have seen, after the joys of untangling what's potentially a very dangerous snake from above head height whilst it's entangled in multiple branches and roots we took it back to our accommodation for processing and it ultimately measured at over 4 feet! Quite large for this species. I still reckon I won that night but I'm sure Stu still believes his bright green viper wins when it comes to attractiveness. My trump card for that argument was that this krait would quite easily and probably has eaten quite a few green-pit vipers in its lifetime, being snake-feeding specialists.

This next mini story, if you want to call it that, gets a little painful (it did for me anyway) and ends quite nicely. Having found the 6 species of venomous snakes in Himachal Pradesh that one could expect to find; spectacled cobra (*Naja naja*), Caspian cobra (*Naja oxiana*), Russell's viper (*Daboia russelii*), Himalayan pit-viper (*Gloydius himalayanus*), white lipped or green pit-viper (*Trimeresurus septentrionalis*) and common krait (*Bungarus caeruleus*), there was one other elapid which I had seen included in one report and after speaking to a villager in the previous year, my belief in its existence in this state was slightly more reinforced. Its identity will be revealed a little later on.

Given that Himachal Pradesh, like many of the other states in India, suffers horrendously from snakebite, documenting another venomous species becomes more important. More important than my desire to see a pretty red and black elapid (ooh, a clue) to photograph.

We arrived at our accommodation in The Great Himalayan National Park, a Forest Department rest house neighboured by pine covered mountains and rivers fit for the most experienced white water

Figure 2. The green pit-viper, *Trimeresurus septentrionalis* found by Stu in 2019. the first species to be found in both 2018 and 2019, both by Stu, which I'm sure he'd want me to point out.

Figure 3. A common krait, *Bungarus caeruleus*. A highly venomous elapid and responsible for numerous fatalities in India. They often make their way into homes during the evening and bite people. Nobody knows for certain why.

enthusiasts. When you initially drive into the park, it almost feels like you're entering the gates of Jurassic Park, you feel tiny. Everything, the mountains, rivers, trees and cliffs are all bigger than what I'm used to seeing back home in Wales. It also does not feel like somewhere you would search for snakes. (figure 4) The climate is almost welsh. Most of the time there's a layer of fog hugging the mountains, it's damp and the temperature isn't all that warm.

However, when the clouds do open up, the sun, being at high altitude is quite warm indeed. That's the difference between here and Wales, and what allows this magnificent scenery to harbour some incredible species of herpetofauna. It's difficult to imagine snakebite being a problem here, we normally hear of people being bitten in the slightly more tropical places around the world; Fer-de-

Figure 4. Views from one of the Forest Department rest houses.

lance in South America, Russell's viper in India and puff adders in Africa. But, bites are frequent in this area and from what we've gathered, it's the Himalayan pit-viper that's the culprit, biting defensively when accidentally stepped on or someone unknowingly places their hand on one when working in their field (figure 5).

Figure 5. Milking a Himalayan pit-viper, Gloydius himalayanus for venom which will later be analysed.

Our goal in this location was to find the Himalayan pit-viper, to sample it's tissue, blood and venom (I don't mean to taste it as I normally would with some whisky per-say). However, it was this village where I had spoken with a villager in the previous year about a red and black snake which hoods. The hooding part had me thinking about species such as the large-eyed false cobra, *Pseudoxenodon macrops* which would have been a huge range extension and a species I very desperately want to see in the wild, one I have also kept in captivity. It was this species that I had at the back of my mind whilst at this location, not my other venomous target, it just didn't fit the bill for me when it came to the conditions and environment here…

The first couple of afternoons were spent walking up and down a couple of trails which backed onto the accommodation. By the second time we had done this and returned, my stomach would start to feel a little uneasy to say the least. Maybe a slight disagreement with food or exhaustion I thought (not something I normally suffer with but I had been in the field for a couple of months and we had done some very serious mileage in that time including a trip over in Nepal). I won't go into too much detail about having to stay back for the next day whilst everyone else was hiking and surveying the nearby area. I don't think you would find any pleasure in reading it and I certainly won't find any happiness in having to re-live it mentally as I type. Now you may understand the title a little more, not the cobra bit. For anybody who hasn't visited India, many of the toilets in India are simply a hole in the ground which feeds directly into a waste pipe. Basically erase your toilet and the hole and plumbing that you have left in the ground, there you have it. I have no issues with this, apart from my lack of flexibility which I'm sure would cause a fly on the wall to choke on laughter as it observes me but with the illness I was currently beginning to feel, I was just glad that we had an actual toilet at this location. It didn't stay that way…

So I was doing the usual sick person things during the day, feeling sorry for myself and making sure to let everyone know that I was ill. Evening arrived, Vishal (the other half of our C&FH Indian expeditions) was cooking one of his usual spicy but incredible West Bengal based dishes, a couple of our volunteers, Ed and Luke had gone for a hike up the mountain trail, Sourish was stuffing his face with pakoras and my girlfriend, Maya was busy listening to me moan about my, at that point, fairly mild, illness (sorry!). The rest house caretaker's phone rang and he immediately called Vishal over. They were speaking in Hindi and I could see that he had received an image on his phone, of a snake. Vishal told me it had come from the village at the top of the hill behind us, the trail that we had previously been hiking led to that village. The one in which I had spoken to the man in the previous year. I knew what this snake was and to say I was excited was a huge understatement. We

Figure 6. MacClelland's coral snake, *Sinomicrurus macclellandi*. Top of our target list and very rarely seen in Himachal Pradesh.

abandoned everything we were doing, I forgot about feeling sick and we all dived in the car. We were unable to get a hold of Ed and Luke so we assumed they must already be up there. These mountain 'roads' are normally quite narrow and about 5 minutes into bumpy journey we were faced by a truck coming down the hill, being a single road, someone was going to have to reverse. This is always a terrifying experience if you happen to be on the side of the road edge, often faced with a drop of 100 meters or more. Sourish and I decided it would be best to get out and run up to the top whilst they figured this out. We hopped out and attempted a jog. Not so easy in flips flops, pouring rain and bowels that have forgotten how to play their role…

What we thought would be a jog of 1km probably ended up being more than twice that. Panting a few hundred meters from the top we get a call from Vishal to tell us not to worry, the villagers have captured the snake. I didn't know whether to cry, with happiness or the fact I was dying, metaphorically. They caught up with us, Sourish and I jumped back into the truck, excited to see this snake. The excitement only lasted so long. There was a crowd of local people surrounding the outside of one of the small mud-walled houses. Upon breaking through them, there it was, the snake I so desperately wanted to see this year! MacClelland's coral snake, *Sinomicrurus macclellandi* (Figure 6). It all seemed a bit too easy, you never come across your target species that early into a trip. Once my breathing came back down to a normal rate (mainly because of the jogging, I'd like to think I can avoid turning into a bulldog when excited and managed to maintain a normal rate of breathing) it was clear that something wasn't quite right. The slender, black and red snake in front of us was not moving in a normal manner. Snakes like this rarely sit this still, usually behaving more like a worm than a snake when disturbed like this. Upon closer inspection of it, it had been pinned down by the person who caught it, a little too heavy handedly, ultimately damaging some vertebrae. Unlikely to survive, I bagged it up, somewhat happy that at least we could collect some valuable data from it. That's when it got interesting, the villager who had captured the snake demanded I give it to him. Confused, I did so to avoid a lynching. He quickly retreated and Vishal explained that, due to our excitement in seeing the snake, this man believed it must have significant monetary value. Something we should all think about when carrying out these kinds of excursions, the last thing we want is for the people at most risk of snakebite to begin collecting them thinking they can sell them.

Luckily, a friend of ours from the Forest Department was able to visit the man and collect the snake for us the next day and explain that he was breaking the law by keeping this snake. So a slightly tragic story but it did allow us to confirm the presence of this species and collect valuable data such as morphometrics and some DNA. I figured we'd eventually find our own, in tact example in following years to come.

It was time to leave the cold and damp mountains of The Great Himalayan National Park and time to travel to an altitude of approximately 2700 meters. A much more arid location, Chamba still receives a lot of rainfall but it's generally hot in the daytime due to the high altitude and open habitat (Figure 7). There's a few reasons that Chamba is my favourite location in Himachal Pradesh; you can finally wash and dry your clothes here, the big mountain valleys filled with raptors riding thermal waves are spectacular, mammal diversity is really high and it's home to none other than the Caspian cobra, *Naja oxiana*.

Reaching Chamba, still feeling ill is not something I ever want to do again. It generally takes us an entire day of driving long, windy mountain roads with very few places to stop for a break, especially a toilet break, I'd like to think I have iron sphincter muscles capable of crushing rocks

Figure 7. A worker taking a break overlooking the magnificent mountain valleys in Chamba.

after that drive. It was at this stage in the expedition were I knew this illness was going to hang around. We had to make a stop at a hospital on route as Maya had symptoms of a kidney infection. Between me making more use of the hospital toilets than anyone else in their and Maya suffering from agonising kidney pain, surely the herp gods would reward us with a cobra to ease us from the suffering? What made the drive even more difficult and long was the numerous landslides. We had visited the state a month or so later than the previous year to determine if there was any change in what we found. This resulted in more rain and with more rain comes more landslides. This often meant we would have to wait as workers would have to arrive and dig a clear path again (Figure 8).

Chamba is always fruitful, we get rat snakes, trinket snakes, vipers which include Himalayan pit-vipers and Russell's viper, although we have also heard rumours of green pit-vipers in some of the greener valleys. Once we had arrived I embraced the luxury of a western toilet again and we got on with our usual routine of road cruising the cliffside roads. One evening, we would separate into two cars to cover a greater distance and time span. Of course, this naturally creates some competition between both 'teams'. Early in, we picked up a stunning, dark chocolatey brown Himalayan pit-viper from the road followed by another and a couple of kukri snakes. Of course, I bragged when

Figure 8. Workers beginning to clear one of many landslides on the drive to Chamba. Caused by frequent rains and steep cliffs.

phoning the other car to see how they were getting on. How couldn't I? I finally had enough courage and energy to leave a larger distance between me and the bathroom, and we had a good handful of snakes.

We arrived back at the accommodation, smug, ready to show off our prized specimens. Luke and Sourish were waiting with a bag in hand, looking equally as smug. They asked me to guess what they had picked up, I went through all of the usual questions; is it venomous? a colubrid? big? small? but nothing matched. Upon opening the bag (which felt completely light and empty, making me think they were ready to prank me) I forgot all about feeling ill. It was a beautiful, bright red and more important, live coral snake! Not something I expected that evening after giving up hope the last time we met with this species. Luke was also quite happy given that this was a target high up on the list for him.

We continued for the next few days searching for more snakes, more coral snakes and of course the Caspian cobra. We searched the same locations as the previous year and numerous new locations but it was not to be in 2019. Landslides and roadworks had decimated many of the roads which we knew the Caspian cobra resided around. Maybe it was our late arrival in the year, maybe it was the disturbance. We will be back there soon, who knows what else we still have to discover in those mountains.

This is a good place to leave this report. There's numerous stories involving encounters with leopards, a bear, a gun and much more but the field report would ultimately take up much more of the journal than the peer-reviewed articles that it focusses on. So for now, I will leave it here and write some other field reports, picking up with some of our many other stories in future issues of the journal. For those of you who are interested, my illness was very likely a case of dengue. I later learned that Nepal was suffering from an outbreak during my visit and my symptoms all fit perfectly, not something I hope to suffer from again. I hope I didn't leave you with too many visual thoughts when describing it.

We also love to hear about your field experiences so if you want to write a field report, get in touch using the contact details on the first page.

A case of caudal autotomy in a captive *Plethodon teyahalee*

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This is a note on the first recorded case of voluntary tail autotomy in a captive *Plethodon teyahalee* (Hairston, 1950). Autotomy, the process where an animal discards a single or multiple limbs, is a common feature found amongst lower vertebrates (Wake and Dresner, 1967; Romano *et al.*, 2010). It is widespread amongst salamander species where it occurs as a defence mechanism against predators and rival animals during competition over territories or mates (Jamison and Harris, 1992; Stebbins and Cohen, 1995; Marvin, 2010; Romano *et al.*, 2010). In salamanders, it is the tail which is autotomised, allowing the individual to escape predation (Stebbins and Cohen, 1995). This specialist adaptation comes with a high cost as the tail is a site of fat storage, as well as aiding in balance and locomotion (Brodie, 1997; Marvin, 2010). It is believed to have evolved from ancestral species which adopted a defensive position by using the tail to distract predators away from the head and/or body (Brodie, 1997).

Within Caudata, there is believed to be a rough grouping of three different types of tail autotomy, and this is defined by how and which part of the tail separates from the body (Wake and Dresner, 1967). Species which have tail breaks, normally towards the posterior of the tail and caused by trauma, are termed 'thick-based tail' species (Wake and Dresner, 1967). Those which are able to autotomise their tail, but only at its base at a localised specific site are the 'constricted-based tail' group, and make up the majority of species (Wake and Dresner,

1967). The final grouping, which includes species of Plethodon are classified as 'Slender-based tail' Salamanders; these species are able to autotomise their tails along its length (Wake and Dresner, 1967).

Figure 1. *Plethodon teyahalee* autotomated tail.

Figure 2. *Plethodon teyahalee* autotomated tail suspended in water.

P. teyahalee is a large, terrestrial, lungless species of caudate which naturally occurs at lower altitudes in the southern Appalachian Mountains, United States of America (Hairston, 1950; Highton, 1995). It is a member of the *glutinosus* species complex which contains multiple species within the Eastern Plethodon grouping (Highton, 1995). Other species within the Eastern clade of Plethodon are known to frequently autotomise their tails as an anti-predator defence and display well-developed 'wound-healing' specialisations (Wake and Dresner, 1967; Highton, 1962). This feature has been widely studied in *Plethodon cinereus* (Green, 1818; Venesky and Anthony, 2007), and has also been recorded in *Plethodon jordani* (Blatchley, 1901; Brodie Jr. and Howard, 1973) and *Plethodon dorsalis* (Cope, 1889; Hucko and Cupp, 2001).

Figure 3. Site of tail autotomation.

In June 2018, a group of five *P. teyahalee* were purchased from a private German collection and brought to the UK, where the animals were placed into a quarantine enclosure. A lack of clear sexual characteristics were present due to the animals either not yet being at sexual maturity (ages unknown) or experiencing unsuitable conditions during their transport. As such, it was not feasible to identify their sex.

After standard quarantine procedure, three surviving individuals were introduced into a permanent, semi-opaque, naturalistic enclosure, which replicates the temperate moist lowland Appalachian mountains (Grover, 1998). Their lungless nature means that they spend much of their time under damp refugia such as rocks and logs (Grover, 1998; Caruso, 2016; Lyons, Shepard and Kozak, 2016). Within the enclosure there are multiple damp hides provided in the form of rotting wood, moss piles and artificial crevices. There is also a dense layer of leaves from multiple species of tree, including *Quercus rober*, *Fagus sylvatica,* and *Anacardium occidentale* providing varying degrees of humidity across the enclosure and sites of refuge. Due to this reliance on dark and moist refugia to avoid

desiccation (Caruso, 2016), overhead lighting is not provided, with natural light being present through a window.
The animals are fed weekly on a mixed diet of commercially available invertebrates; brown field crickets (*Acheta domesticus,* Linnaeus, 1758), calci worm larvae (*Hermetia illucens*, Linnaeus, 1758), waxworms (*Galleria mellonella*, Linnaeus, 1758), mealworms (*Tenebrio molitor*, Linnaeus, 1758), fruit flies (*Drosophila melanogaster*, Meigen, 1830) and silk moth larvae (*Bombyx mori*, Linnaeus, 1758). Brown field crickets and fruit flies are dusted on an *ad hoc* basis with 'Nekton MSA' supplement powder.

Prior to this feeding activity, the animals are located and checked for signs of ill health with minimal contact. This activity is carried out in low light as is the feeding, and takes place in the evening which is aimed to replicate the period of time when the species naturally emerges to hunt (Lyons, Shepard and Kozak, 2016). This activity of feeding and observing the animals is kept to a shortened period of time (<30 minutes) to minimise disturbance and occurs at a maximum frequency of once a week.

On Monday the 28th of January 2019, at 23:15pm, during feeding and health checking activity, it was found that one individual had autotomised its tail. Animals had not been fed or disturbed for a period of 10 days prior to this event. The site of skin breakage was straight with smooth edges and a folded flap of skin had depressed over the edge of the wound (Fig. 1) with no sign of predation by invertebrates or other *P. teyahalee*. The animal was located under a piece of refugia and exhibited normal signs of mobility and retreat at being discovered. The wound itself was clean and no blood was observed to be leaving the wound.

The tail was located in a different part of the enclosure (Fig. 2 & 3). Upon removal it was observed that the last 1.5cm of the tail had mobility and slowly moved left and right a single time in each direction before movement stopped. The tail also had no clear signs of predation upon it, and no other *P. teyahalee* were found within the immediate vicinity.

Figure 4. Posterior image of *Plethodon teyahalee*

The autotomised tail length measured 7.1cm upon discovery, with roughly 1.8cm of tail remaining on the animal (SVL of 6.5cm). The site of tissue breakage was at a point closer to the base of the tail than the skin breakage, causing some skin tissue to overhang. Exposed vertebrae were seen to be protruding from the wound on the animal, and at the anterior of the tail where the attachment should have been, there was apparent musculature; as such it is believed that it was autotomised. This is a hallmark of slender-based tail species of Plethodontid, which do not localise tail breakage sites only to the base, but at variable sites, and confirms *P. teyahalee's* placement within the slender-based tail group and also Plethodon (Wake and Dresner, 1967; Mueller *et al*., 2004).

The animal was then observed on the 29th of January 2019, at 18:30pm and on the 9th of February 2019, at 19:55pm and showed no signs of ill health, displaying the normal behaviour of retreat to refugia (Fig. 4 and 5).

Figure 5. *Plethodon teyahalee* with autotomatised tail.

The wound site on this occasion was dry, and on one side the skin which had been overhanging had clearly bonded, starting the process of healing. This sign of wound-healing further reinforces *P. teyahalee's* placement within slender-based tail Plethodontids (Piersol, 1910; Wake and Dresner, 1967).

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A Study of Reptile Road Mortalities on an Inter-state Highway in The Western Ghats, India and Suggestion of Suitable Mitigation Measures

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Abstract:

Western Ghats, a global biodiversity hotspot, provides habitat for several endemic species that may be threatened due to high numbers of road mortalities because of vehicular collisions. Several studies have shown that amphibians and reptiles, grouped together, experience the highest number of road mortalities as compared to all other animal groups, thus affecting their populations worldwide. I studied animal road mortalities in Western Ghats along an interstate highway that connects the states of Kerala and Karnataka, and had previously been opportunistically recorded to have several snake road mortalities. This study shows that reptiles experienced the highest number of road mortalities as a group, followed by mammals. Within the class of reptiles, snakes were the most affected with several endemic species being killed within a duration of eight days. I henceforth identified four locations with higher numbers of snake road mortalities along the study route. In this study, I also thoroughly review the mitigation strategies for reptile roadkill and suggest suitable ones for the study site. Implementation of these strategies by the forest department and local NGOs can help reduce roadkill to a great extent and help retain viable populations of several endemic reptile species in the Western Ghats. These strategies can help mitigate reptile road mortalities in other regions as well by adopting a few, simple, cost-effective measures post road construction.

Key Words: biodiversity hotspot, endemic, herpetofauna, roadkill, snakes, Kodagu

Introduction:

The ever-expanding human population and consequent development has led to an increased number of roads cutting through forested areas and impacting the ecosystem as a whole. Roads can have several ecological effects on flora and fauna of the region (Trombulak and Frisell 1999). They can lead to the formation of a barrier to dispersal of animals due to habitat fragmentation (Seshadri and Ganesh 2011). This can eventually subdivide their populations and lead to inbreeding depression or other demographic and genetic effects (Forman and Alexander, 1998). Habitat fragmentation has also increased the susceptibility of animals to roadkill due to vehicular collisions (Langton 1999; Glista 2009). A study on *Felis pardina* (Iberian Lynx) found that road mortality can exceed mortality due to natural causes (Ferreras *et al*. 1992). But some researchers believe that the barrier effect due to roads is more important than direct vehicular collisions when considering the impact of roads on animals (Forman and Alexander 1998). Apart from habitat fragmentation and road mortality, roads also impact animals by causing changes in their physical and chemical environment, and changing their behavior and dispersal patterns (Trombulak and Frisell 1999; Karunarathna 2013).

There have been numerous studies on the number of roadkills in different parts of the globe (Vijayakumar *et al*. 2001; Glista *et al*. 2008; Hartmann *et al*. 2011; Samson *et al*. 2016) and it has been found that millions of animals are killed annually due to expansion and construction of roads around the world (Narayanan *et al*. 2016; Bujoczek *et al*. 2011), making the need to address road mortality an integral part of conservation.

Some animal populations face major levels of mortality due to direct vehicular collision (Trombulak and Frisell 2000; Glista 2008, 2009). Although animals with higher population abundance and high reproductive rates may not be significantly affected by roadkill (Forman and Alexander 1998), threatened or endangered species with small population sizes, and endemic ones may get affected severely leading to their local and global extinction (Spellerberg 1998; Glista *et al*. 2008; Row *et al*. 2007; Seshadri and Ganesh 2011). Examples of such studies include the study on the American Crocodile (*Crocodylus acutus*) by Kushlan, 1988 and another one on the Florida Panther (*Felis concolor coryi*) by Foster and Humphrey, 1995.

Most roadkill studies were initially focused on large animals such as carnivores and ungulates (Glista *et al*. 2008) but now there is increasing awareness about herpetofauna (reptiles and amphibians) being a major group impacted by roadkill (Ashley and Robinson 1996; Glista *et al*. 2008; Selvan *et al*. 2011; Arévalo *et al*. 2017).

This has also been made evident in the Indian subcontinent by multiple studies in the past which recorded mortalities of animals, especially herpetofauna, due to roadkill in the Western Ghats region (Gokula 1997; Samson *et al*. 2016; Narayanan *et al*. 2016). The Western Ghats region of India, considered as one of the 'hottest hotspots' of biodiversity in the world (United Nations Educational,

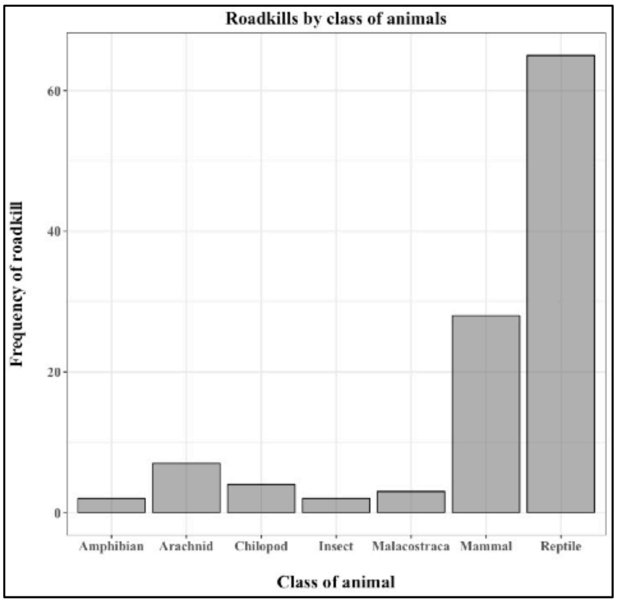

Figure 1. Frequency of roadkill by taxonomic class of animals during an eight-day period from 31 August 2017 to 07 September 2017 on an 18.3 km stretch [Perumbadi lake (12.142243N, 75.795335E) to Kerala RTO check post (12.073331N, 75.723526E)] of the Kannur-Mattannur-Coorg Road, Kodagu, Karnataka, India.

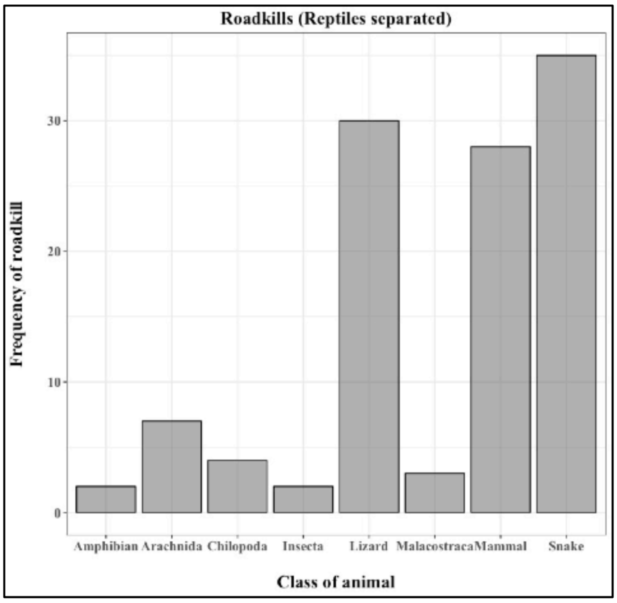

Figure 2. Frequency of roadkill of lizards and snakes separated compared to other taxonomic classes of animals during an eight-day period from 31 August 2017 to 07 September 2017 on an 18.3 km stretch [Perumbadi lake (12.142243N, 75.795335E) to Kerala RTO check post (12.073331N, 75.723526E)] of the Kannur-Mattannur-Coorg Road, Kodagu, Karnataka, India.

Scientific and Cultural Organization [UNESCO] World Heritage Centre. 1992. Available from https://whc.unesco.org/en/list/1342 [Accessed 18 December 2018]), is home to a large number of endemic plant and animal species (Myers 2000) especially reptiles and amphibians (Inger and Dutta 1986;

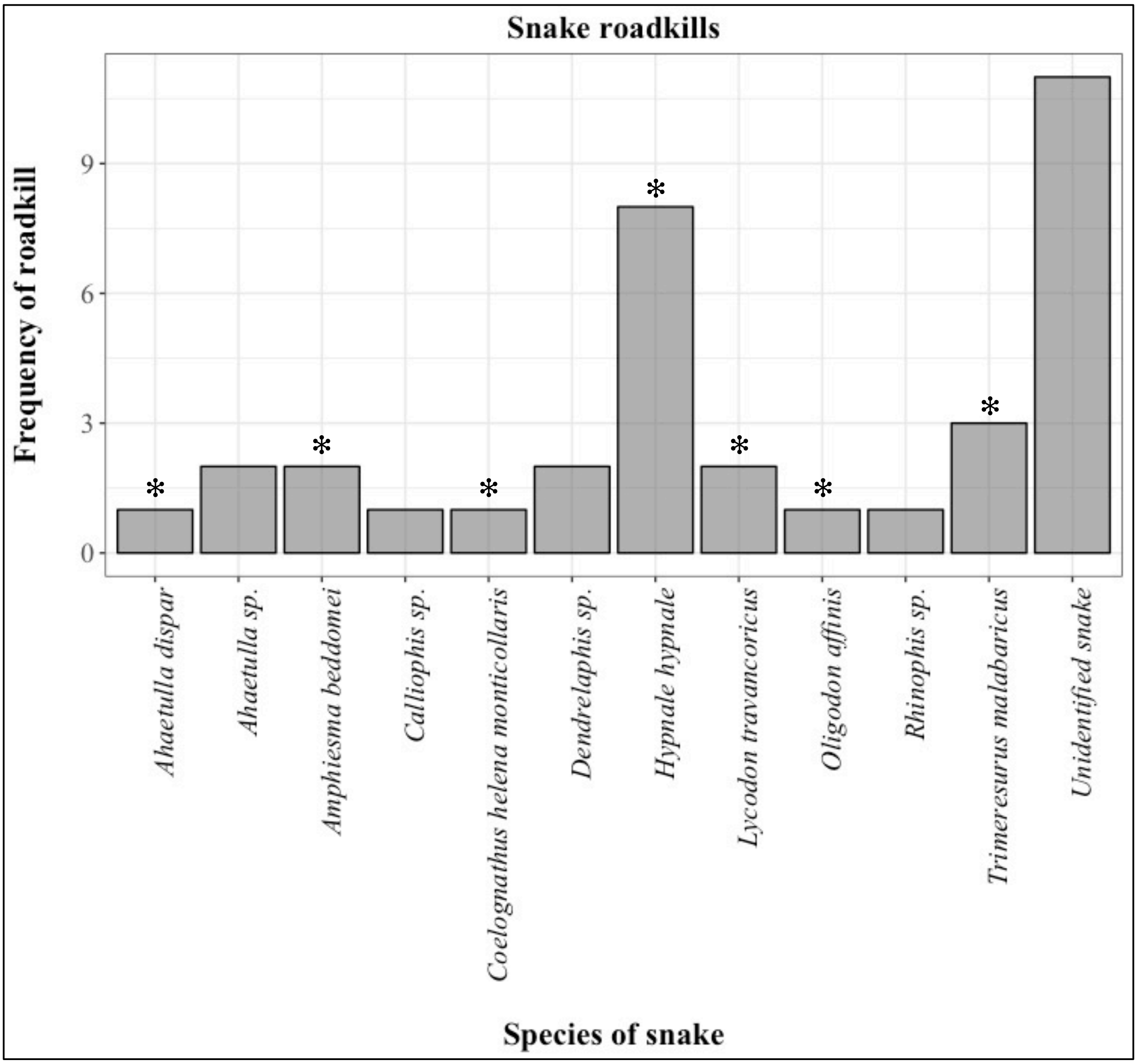

Figure 3. Frequency of roadkill of different species of snakes during an eight-day period from 31 August 2017 to 07 September 2017 on an 18.3 km stretch [Perumbadi lake (12.142243N, 75.795335E) to Kerala RTO check post (12.073331N, 75.723526E)] of the Kannur-Mattannur-Coorg Road, Kodagu, Karnataka, India. The asterisk denotes endemic species of the Western Ghats. It is worth noting that all snake carcasses identified to the species level in this study are endemic to the region.

Vijayakumar *et al*. 2007). It provides shelter to about 325 or more globally threatened species and is also identified as a World Heritage Site by UNESCO (UNESCO World Heritage Centre. 1992. *op. cit*.). Such landscapes and the species therein are particularly sensitive to human encroachment, roads being one of the major issues as they improve connectivity leading to higher disturbance.

This study focuses on another area of the Western Ghats where opportunistic data had previously indicated a high mortality of snakes on the road. My study had the following objectives:

(1) To determine the number of herpetofauna mortalities on the Kannur-Mattannur-Coorg Road caused by vehicular collisions.

(2) To find out if reptiles, especially snakes, were particularly affected.

(3) To identify regions of the road with higher density of road mortalities of snakes.

(4) To suggest suitable mitigation strategies along the route for implementation by the

Forest Department.

Materials & Methods:

Survey site - I conducted the survey on an 18.3 km stretch of the Kannur-Mattannur-Coorg Road, Kodagu, Karnataka in the Western Ghats, India (refer to Appendix 1). The road connects the two states of Karnataka and Kerala and passes through the Brahmgiri Wildlife Sanctuary. The habitat is mostly tropical evergreen moist rainforest but a few rubber plantations exist in some roadside areas. Sampling was started right after Perumbadi lake (12.142243N, 75.795335E) and carried out up until the Kerala RTO check post (12.073331N, 75.723526E).

Survey method - I surveyed the route from 31 August 2017 to 07 September 2017 starting at Perumbadi lake at 0830. I surveyed on a motorbike with one person riding the bike along the extreme left of the road at the speed of 10±5 km/h while I sat behind and scanned the road. I photographed all dead animals, irrespective of their class, above the size of about 1.5-2 cm, as found on the road and after turning, to aid species identification. I recorded the GPS location (in DMS) and then removed the carcass from the road to avoid repeated counting. Where possible, I identified and recorded the species of the road killed snake on the spot using the field guide by Whitaker and Captain, 2015. When specimens were not easily identifiable in field, I identified them later by referring to an online snake database (Indiansnakes.org. Available from http://www.indiansnakes.org/ [Accessed 20 October 2017]) and the field guide by Whitaker and Captain (2015), using the photographs taken in field. I usually took about four hours to complete the survey each day, which varied depending on the number of dead animals found. The rider also helped in spotting animal carcasses on the road during the survey. As the main focus of the study was on snakes, I identified road killed carcasses for snakes to the lowest taxonomic level possible. For other animals, I usually identified up to the genus level.

Data analysis -

1) *Identifying the group with maximum mortality*

I analysed the collected data using RStudio (Version 1.1.383; R Core Team 2017). To check if a particular class of animals was more affected as compared to others, I plot the number of roadkills for each class and compared their numbers. I also did the same to check if snakes, as a separate group, were affected more than any other animal as had been speculated based on opportunistic data from previous visits to the area.

2) *Identifying regions with higher density of snake road mortality*

I converted the location data for roadkill to decimal degrees (DD) from degree minute second (DMS) format in RStudio (Version 1.1.383; R Core Team 2017). Then I overlaid this data on the road map of the study site using the QGIS software (Version 2.18; QGIS Development Team 2017). Next, I generated a heat map with a radius of 0.0001 map units (10.247─11.132 m) for data on snakes and then detected hotspots by setting a suitable threshold based on the heat map (threshold = 1).

Results:

During this study, I recorded a total of 117 road killed animals over a period of eight days along the 18.3 km route which amounts to a total of 146.4 km.

1) *Group with maximum mortality*

Due to difficulty in assigning any identity for six roadkills, I eliminated them before conducting further analysis. Reptiles faced much higher mortality than any other class of animals (58.04%) followed by mammals (25%) (Fig. 1). When I separated lizards and snakes and plot them along with other classes, snakes showed the highest number of mortalities (31.25%) followed by lizards (26.79%) which is still higher than other classes without any group separation therein (Fig. 2). Of course, these numbers would be truly comparable only amongst the animal classes of comparable body size and having equal detection probabilities which is affected by various factors as discussed later. Figure 3 shows that amongst snakes, *Hypnale hypnale* (Hump-nosed Pit Viper) experienced highest road mortality but several other endemic species such as *Oligodon affinis* (Western Kukri), *Coelognathus Helena monticollaris* (Montane Trinket Snake), *Amphiesma beddomei* (Beddome's Keelback), *Trimeresurus malabaricus* (Malabar Pit Viper) were also killed due to vehicular collision.

Mammalian road mortalities included the *Moschiola indica* (Indian Mousedeer), *Macaca radiata* (Bonnet Macaque) and some unidentifiable rat and bat species.

2) *Regions of high animal road mortality*

The map with overlaid points of all animal roadkills shows that the whole stretch of road surveyed experienced animal road mortalities (refer to Appendix 2). Four regions were found to have more than one snake road mortality which may be due to chance in this study because of low sample size and would need to be confirmed with further observations (Fig. 4).

3) *Detection bias due to cloud cover*

While surveying, one of the factors I thought could affect detection of roadkill was sunlight. Thus, I conducted a Spearman rank correlation test to statistically determine any correlation between cloud cover and number of roadkill found. I found no correlation between the total number of road mortalities and cloud cover within the dataset (ρ = -0.64, P = 0.10) nor between the number of snake roadkills and cloud cover (ρ = -0.36, P = 0.38).

Discussion

This study found that the study route has a substantial number of road mortalities. There were 117 road mortalities in 8 days. If the average rate of road mortalities remains the same throughout the year, the total number of mortalities each year would reach more than 5000.

Reptiles had the highest road mortalities followed by mammals. This result can be explained using several reasons. Reptiles being ectothermic animals often use behavioral thermoregulation. The tar roads heat up during the day and the heat is released slowly at night. This attracts nocturnal reptiles to the roads for thermoregulation of their body temperatures (Bernardino and Dalrymple 1991; Bamabaradeniya *et al*. 2001; Selvan *et al*. 2011; Karunarathna *et al*. 2013). Many of the road killed snakes found during my study were in a coiled position instead of being stretched out like some others, which may suggest that some were thermoregulating on the road while others were probably just crossing it. It has also been suggested that reptiles may be laying eggs along road edges for similar reasons (Karunarathna *et al*. 2013). Roads in dense canopy forests can provide gaps where sunlight penetrates well to the ground during the day. This could be the reason for diurnal reptiles to be seen basking on the road and for their higher mortality. Numerous individuals of the genus *Calotes* observed along the sides of the road during the survey may provide one such example. The small size of the reptiles compared to large mammals which can be easily seen by approaching vehicles could be another reason. Since the route studied had been renovated such that there is high speed traffic now, the reptiles would go unnoticed most of the times and be run over.

TABLE 1: Summary of suggested roadkill mitigation strategies

Category	Mitigation strategy	Importance	References
Animal behaviour modification	Culverts/Underpasses/Hose-bridges • At identified hotspots • 0.5m diameter • 0.6-0.9 m high drift fences • Light source	Safe crossing by animals	Brehm 1989; Bernardino and Dalrymple 1991; Aresco 2005; Glista et al. 2008, 2009; Woltz et al. 2008
Animal behaviour modification	Metal cover boards Place metal cover boards at regular intervals (100 m) along road-side.	Refuges for thermoregulation	James Warren, pers. comm.
Animal behaviour modification	Strumming of vegetation Push the forest edge away from road by clearing vegetation up to 5-10 m on either side of road.	Non-road open canopy areas for basking	James Warren, pers. comm.
Human behaviour modification	Reduction in traffic volume Restriction on number of vehicle entry per day, especially on festival days and holidays.	Less traffic faced by animals	Seshadri and Ganesh 2011
Human behaviour modification	Temporary road closure During breeding season of snakes and at night when roads are hotter compared to the surrounding areas, the roads should be completely barricaded.	Less traffic faced by animals	-
Human behaviour modification	Speed limit Reduction and strict implementation of speed limit which can be aided by sign boards and speed bump construction.	Time to escape	Glista et al. 2009; Seshadri and Ganesh 2011; Samson et al. 2016

Within reptiles, the highest road mortalities in snakes can be explained by additional reasons. When crossing roads to move between fragments of habitats (Langton, 2002; Karunarathna *et al*. 2013) they have lesser mobility as compared to lizards which tend to escape from approaching vehicles (Bambaradeniya *et al*. 2001; Karunrathna *et al*. 2013). Snakes tend to coil up on detecting vibrations of vehicles and hence get killed (Bambaradeniya *et al*. 2001; Karunrathna *et al*. 2013). In India, snakes are often resented by the general public due to the extremely high number of snake bite cases leading to injuries and deaths and thus many people can be seen riding over the snakes, intentionally, on detection. Aggressive behavior of drivers towards snakes on roads has also been documented before (Bambaradeniya *et al*. 2001; Karunrathna *et al*. 2013).

Although, this study does not support many other studies which have found amphibians to be the major group of impact (Vijayakumar *et al*. 2001; Arévalo *et al*. 2017), it does provide support to some studies which found reptiles to be the major group of impact (Selvan *et al*. 2011; Karunarathna *et al*. 2013). The differences could be explained by local abundance of reptiles in the study area and the extremely small size of some amphibians. Uncertainty in identification of completely destroyed animal carcasses on the road could also have played a major role in leading to this bias. Some studies suggest that carcass persistence on roads is the major factor in estimate biases during roadkill surveys (Coelho *et al*. 2008; Santos *et al*. 2011) where persistence is higher for larger animals as compared to smaller animals (Balcomb 1986; Wobeser and Wobeser 1992; Santos *et al*. 2011). The above-mentioned studies also suggest that carcasses for smaller animals usually persist for a day. This study was designed to maximise detection of smaller animals because of their previously known local abundance and thus the survey was conducted every 24 hours, eliminating most possibilities of missing carcasses. Hence, lower persistence of smaller carcasses could not be a possible cause of lower amphibian road mortalities as found in this study. But a study by Aresco *et al*. (2005) suggests that detecting some small anuran species road kills may be difficult due to their tendency to get stuck on tyres or get completely destroyed. Therefore, the low abundance of amphibian mortality data either indicates their low abundance in the area, avoidance of roads, mortality of only very small anuran species or some other reason which would need further investigation.

Since the ecology and behavior of each taxon varies, a generalized analysis of road kill hotspots would not help devise meaningful mitigation strategies. A heat map analysis for reptiles showed a somewhat uniform spread of the road kills and hence did not reveal significant values for identification of hotspots (refer to Appendix 3). This study was thus focussed on snakes due to expertise in the field and their local abundance. The regions with more than one snake road mortality were marked. Even though four such regions were identified using GIS heat map analysis, the data is insufficient to draw proper conclusions since the threshold used in the analysis for calculating hotspots was low (threshold = 1). Eberhardt *et al*. (2013) also suggest the unreliability of hotspots analysis. They suggest that often areas with highly suitable habitat for a species may have seen a population decline due to road kills in the past and hence may not appear as a hotspot in the analysis of a more recent dataset for road mortalities in the region (Eberhardt *et al*. 2013). Such regions still need to be taken into account when suggesting mitigation strategies and hence not much focus should be placed on hotspot analysis. Nevertheless, a long-term monitoring study or additional short-term studies carried out during different seasons may help confirm the locations of hotspots identified in this study for snake road mortalities. A similar analysis with more data could also reveal certain areas with higher *Macaca radiata* (Bonnet macaque) deaths since they were often observed in groups around areas of higher human disturbance.

However, there can be several factors affecting the observations of this study. For example, higher temperatures may lead to drying of the carcasses beyond recognition while high precipitation could wash them away. Thus, these factors need to be taken into account when designing sampling method for a given area.

The correlation between cloud cover and number of road mortalities was checked to ensure that there was no detection bias between shaded and sunny area as was speculated during the survey. Cloud cover does not seem to have had any effect on the number of animal road mortalities detected during the sampling period of this study.

There could still be some other factors affecting the numbers in the survey. Some carcasses may have moved away from the road or been picked up by scavengers before being detected which can cause underestimation of the number of roadkills (DeVault *et al*. 2003; Smith and Dodd 2003; Glista *et al*. 2008) along with the lower efficiency of driving surveys compared to walking surveys (Langen *et al*. 2007). Identification of road killed animals is an extremely daunting task since most specimens are flattened and laden with mud from the vehicle tyres and tar from the road. Thus, it was very difficult to identify several snake specimens, henceforth inhibiting proper interpretation of (Fig. 3). These issues are characteristic of roadkill studies and much cannot be done to resolve them.

Directions for Future Studies in the Area:

Several studies have shown a correlation of number of road mortalities of animals belonging to different taxa with weather variables (Smith and Dodd 2003; Glista *et al*. 2008; Narayanan *et al*. 2016). Glista *et al*. (2008) showed that temperature and precipitation played a major role in determining the number of road mortalities with peaks during highest temperature and precipitation months. Other studies discuss the species specific seasonal variation in number of road mortalities which may be due to mate searching and juvenile recruitment in snakes (Hartmann *et al*. 2011) and distinct life histories of anuran species (Ashley and Robinson 1996; Glista *et al*. 2008) for example. The volume of traffic has been another determinant for the number of road mortalities in some studies which show a positive correlation between the two (Bernardino and Dalrymple 1991; Seshadri and Ganesh 2011; Arévalo *et al*. 2017). The study by Santos *et al*. (2011) also talks about the effect of traffic and weather conditions on the estimation of the number of road mortalities. Traffic can have a positive correlation with the number of road mortalities detected not only due to more animals being run over but also because more traffic results in lesser access of the carcasses to the scavengers (Slater 2002; Santos *et al*. 2011). Similarly, the weather conditions can also increase the number of road mortalities detected due to lower scavenger activity in poor visibility conditions such as fog or rain (Hels and Buchwald 2001; Slater 2002; Coelho *et al*. 2008; Santos *et al*. 2011). Thus, further studies in the area are required to check for any effects of season, weather, species specific behaviors and traffic on the number of road mortalities to be able to suggest better suited mitigation strategies such as temporary closure of the road.

Mitigation Strategy:

The data collected in this study is sufficient to indicate the need for mitigation strategies for road mortalities of animals since the number is astonishingly high for an eight day period and many important, endemic species were also found dead. If roadkills occurred at the same rate, throughout the year, as observed during

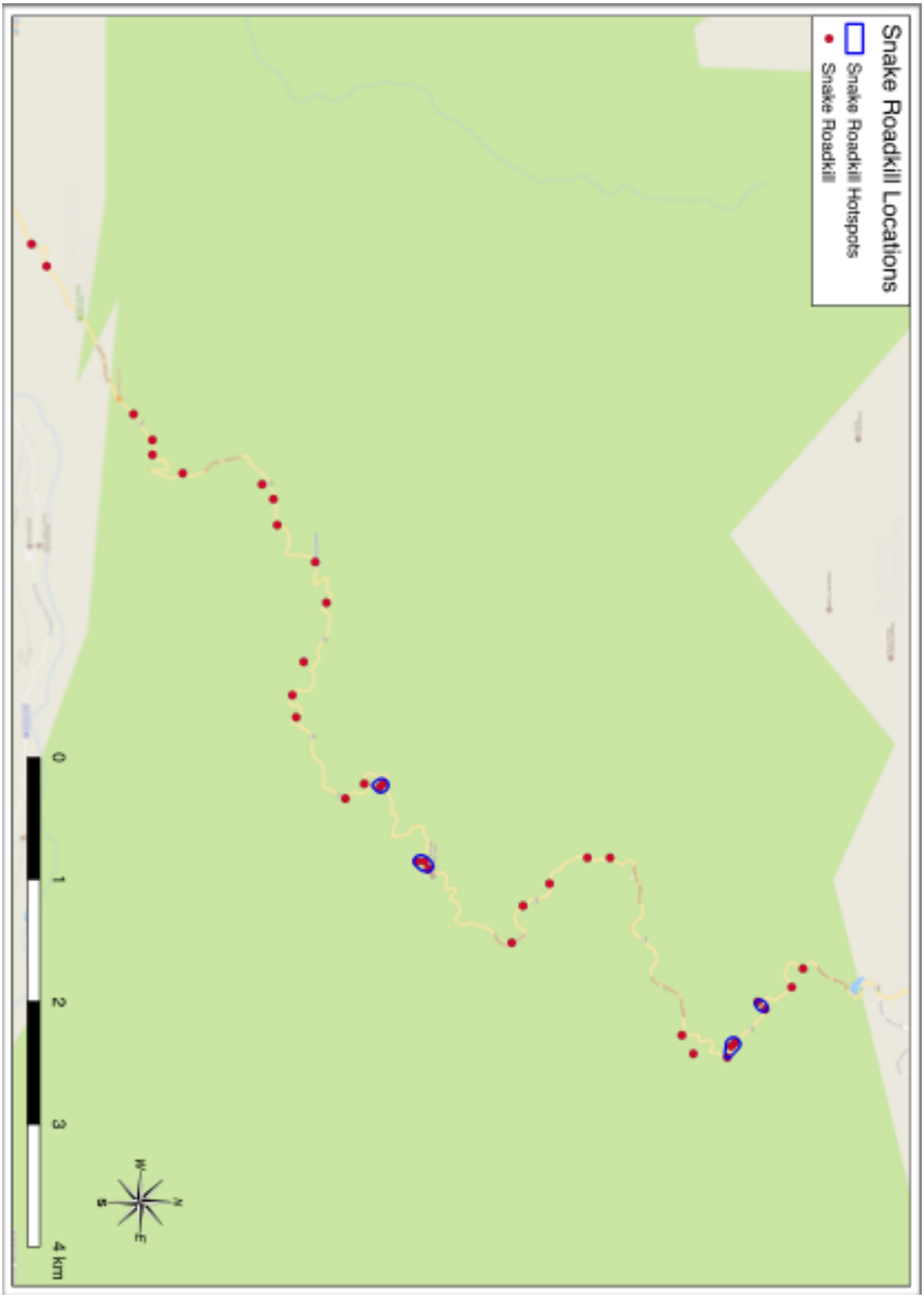

Figure 4. Map showing snake roadkill locations along the 18.3 km stretch of road surveyed [Perumbadi lake (12.142243N, 75.795335E) to Kerala RTO check post (12.073331N, 75.723526E)] of the Kannur-Mattannur-Coorg Road, Kodagu, Karnataka, India. The blue circled areas denote the identified hotspots for snake roadkills (base map used: Google street maps).

Figure 5. Photographs of roadkills taken during the survey. A: *Ahaetulla sp.*, B: *Calotes sp.*, C: *Calliophis sp.*, D: *Dendrelaphis sp.*, E: *Moschiola indica*, F: Bat (species unidentifiable), G: Caecilian (species unidentifiable). (Photographed by Udita Bansal).

the study period for this study, a simple calculation shows that the number of total roadkills would reach 5338 in a single year. As previously mentioned, the effect of roadkill can be drastic for endemic species which can go locally extinct (Vijayakumar *et al*. 2001; Glista *et al*. 2008; Seshadri and Ganesh 2011) due to such unnatural causes of population decline which far exceed the rate of mortality due to natural causes (Ferreras *et al*. 1992). Thus, some mitigation strategies are hereby suggested for reptiles as the main focus group. Mitigation strategies have been grouped into two categories by Glista *et al*. (2009) based on the modification of the animal or the motorist behavior. The first category can include strategies such as culverts and other animal crossing structures, cover boards and strumming of vegetation. Regulating volume of traffic, temporary closure of roads, enforcing speed limits, putting up sign boards and speed breakers can be part of the second category.

Culverts have been suggested by several authors as means of letting animals move across fragments of habitats on either side of the road (Aresco 2005; Glista *et al*. 2008, 2009; Woltz *et al*. 2008). They may be avoided by some large animals (Glista *et al*. 2009) but since this study shows a majority of small animal road mortality in the study area, they can be adopted effectively in this case. As location of the culverts has been implicated to be a major factor in their effectiveness for herpetofauna and other less mobile, small animals (Glista *et al*. 2009), locations identified as having higher density of snake road mortalities in this study should be further checked and can be installed with medium sized diameter (Woltz *et al*. 2008) culverts.

Underpasses can also be used in place of culverts along with drift fences or barrier walls (Brehm 1989; Bernardino and Dalrymple 1991; Glista *et al*. 2009). These underpasses can have openings on their upper surfaces for penetration of natural light and maintenance of natural temperature conditions to prevent avoidance by animals (Brehm 1989; Bernardino and Dalrymple 1991).

Hose-bridges which are easier to install post road construction as temporary structures are a recent development in this field. They act as speed breakers for vehicles and also allow snakes to pass through safely when directed towards the different sized tunnels using drift fencing (Manka 2016). These structures have an advantage of easy installation, possibility of shifting due to changes in hotspots of roadkills, and natural light conditions due to provisions of slits or holes (Manka 2016). Thus, in regions of the road where snake mortality is the primary concern, these structures can prove to be easy solutions for safe snake crossings.

To prevent reptiles from basking on the road, metal cover boards can be placed along road sides to provide places for thermoregulation. If permissible, the vegetation on either side of the road can be strummed to push the habitat edge inward and away from the road to help keep the animals away from the road (James Warren, pers. comm.).

Apart from modifying animal behavior, an effective solution can be to regulate the volume of traffic on the road by putting restrictions on the number of vehicles allowed to enter the route each day along with promotion of public transport usage on this particular route (Seshadri and Ganesh 2011). The road can be temporarily closed during breeding seasons of snakes and during the night when there may be high number of nocturnal snakes on the road for thermoregulation. Reducing the speed limit and its proper enforcement can help reduce mortalities (Glista *et al*. 2009; Seshadri and Ganesh 2011) since high-speed traffic has been implicated as a major reason for roadkill (Glista *et al*. 2009). It can give animals enough response time to escape (Seshadri and Ganesh 2011) and also the drivers to apply breaks and bring the vehicle to a halt. Speed bumps can be constructed at regular intervals to ensure enforcement of speed limits (Glista *et al*. 2009; Samson *et al*. 2016) and sign boards put up to indicate wildlife crossing areas and remind people about the speed limit (Glista *et al*. 2009; Seshadri and Ganesh 2011; Samson *et al*. 2016).

A serious problem observed along the route of the survey was feeding of the Bonnet Macaques by tourists who often stopped on their journeys to take a break and have a meal. This not only created areas of Bonnet Macaque concentration, possibly altering their ecology and behavior, but also resulted in littering of the forest. Such activities should be kept under strict check in protected areas of such high endemic value. Sign boards can be put up in the local languages to spread awareness but regular patrolling by the forest department and placement of fines will be necessary. Halting of vehicles along the 18.3 km stretch should not be permissive and short cemented pillars along the road can help block spaces for parking cars.

All the above-mentioned strategies have been summarized in Table 1.

With massive number of roadkills in India happening by the day there has been an increased awareness about the issue. A recent citizen science initiative has been taken to increase further awareness and get roadkill data from across the country. An Android application, named “Roadkills”, which lets you report roadkill data along with images and location has been launched by Wildlife Conservation Trust. The data is openly available for use by NGOs and the government and hence can reduce the need of carrying out surveys by researchers who can then focus on devising suitable mitigation strategies by analysing the collected data. It is one of the first such applications in India and is a huge step towards reduction of animal road mortalities.

Conclusion:

With substantial number of animal road mortalities along the survey route passing through a protected area in the Western Ghats, it is imperative to take action to prevent local extinction of endemic reptilian species. If preservation of natural forested habitats is not entirely possible, roads should be constructed bearing in mind the consequences animals face. Appropriate strategies should be adopted during and after road construction to allow safe passage of animals across the roads. It has been shown that overall mitigation measures are effective in reducing roadkill by 40% (Rytwinski *et al*. 2016) and hence the strategies suggested here, after careful survey of the roadkill in the region, should be implemented by the forest department. The strategies suggested are all very economical and just require stricter implementation of existing laws in some cases. Further studies may be done in the area to check for seasonal differences and the effect of traffic volume but till then this study shall suffice to suggest the need and the kind of mitigation measures to be implemented to reduce animal roadkill in the region.

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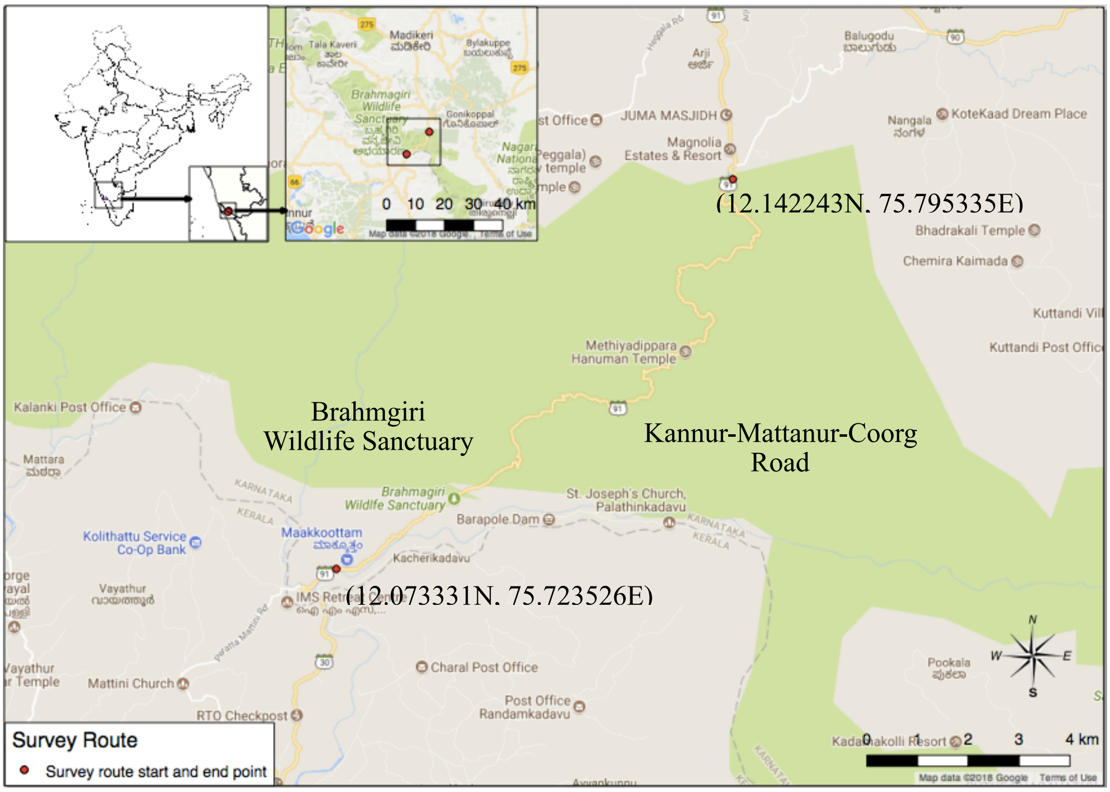
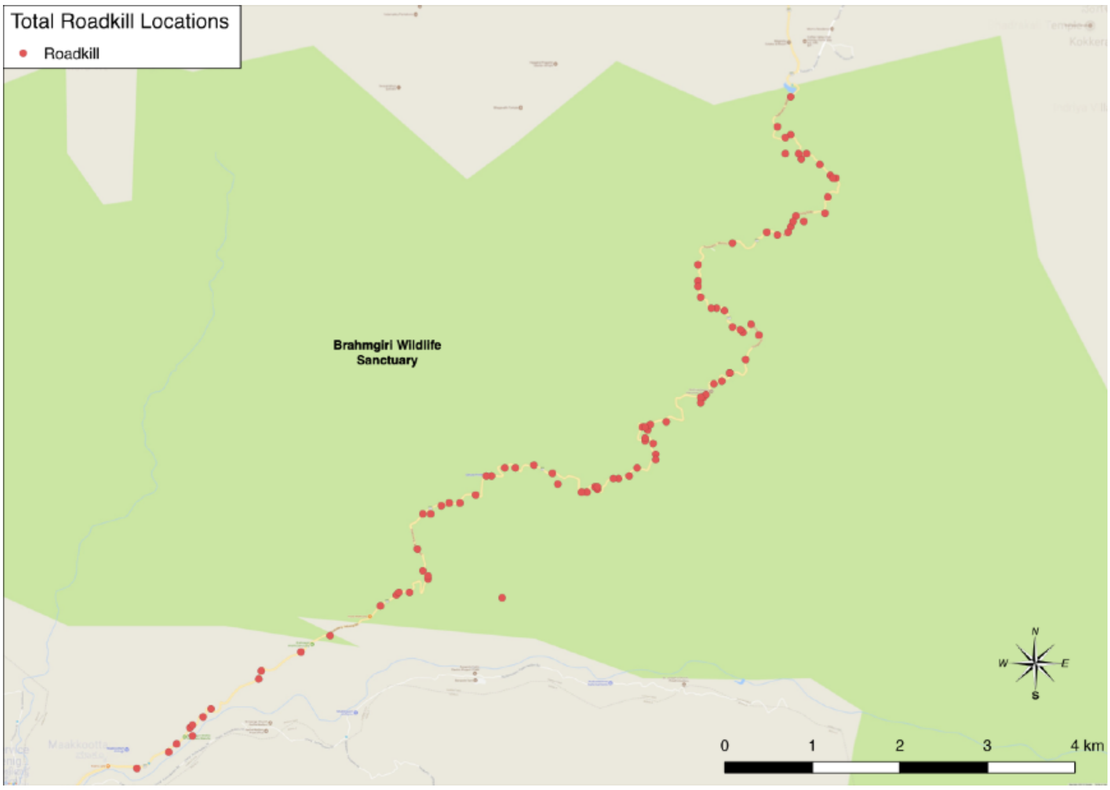
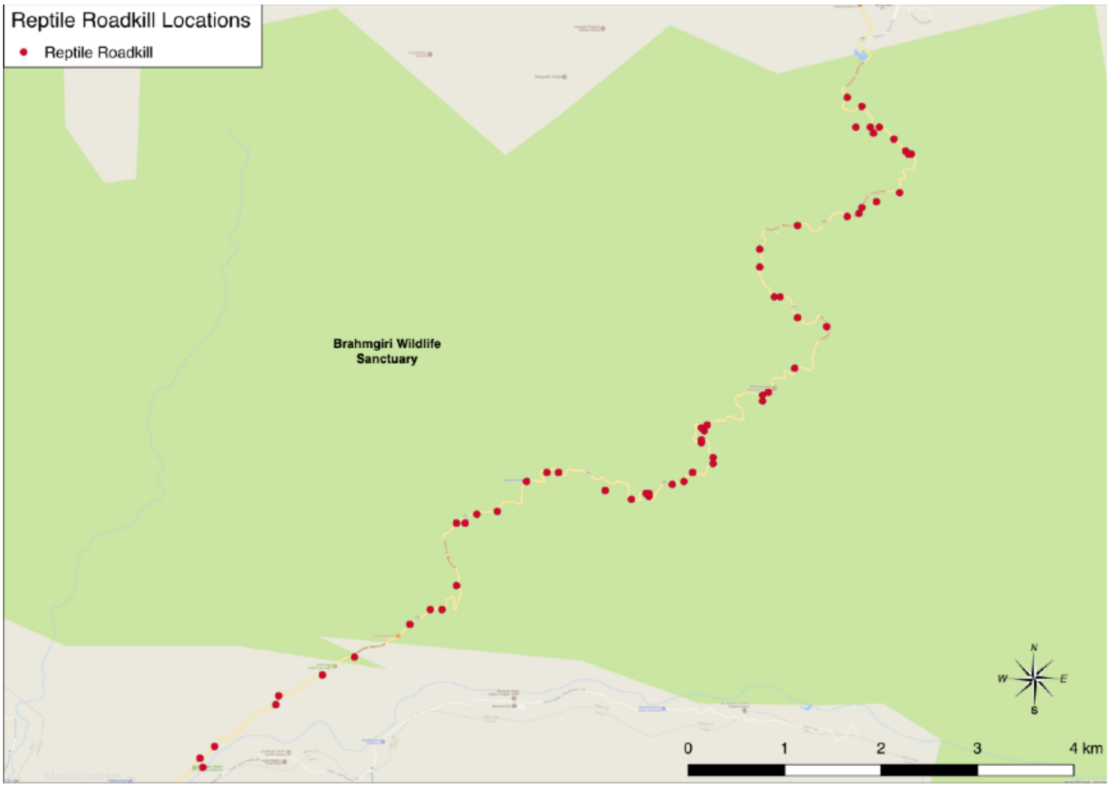
Appendices



Appendix 1. Map of the survey site. The red points demarcate the 18.3 km stretch of the Kannur-Mattannur-Coorg Road that was surveyed from 31 August 2017 to 07 September 2017 in Kodagu, Karnataka, India. The upper red point denotes Perumbadi lake (12.142243N, 75.795335E) which was the survey start location, and the lower red point denotes the Kerala RTO check post (12.073331N, 75.723526E) which was the survey finishing location.



Appendix 2. Map showing location of all roadkills along the survey route during a period of eight days from 31 August 2017 to 07 September 2017. The survey route was an 18.3 km stretch of the Kannur-Mattannur-Coorg Road, Kodagu, Karnataka, India.



Appendix 3. Map showing location of only reptile roadkills along the survey route during a period of eight days from 31 August 2017 to 07 September 2017. The survey route was an 18.3 km stretch of the Kannur-Mattannur-Coorg Road, Kodagu, Karnataka, India.

An Observation on Diet of the Cameron Highlands Pit Viper (*Trimeresurus* (*Popeia*) *nebularis*)

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Trimeresurus nebularis is a medium-sized nocturnal venomous snake that resides in montane forests at altitudes above 1200 m elev. Once thought to be an endemic to the Cameron Highlands of Pahang state, Peninsular Malaysia (Vogel et al. 2004.), it has since been recorded at other hill stations within the country as well as Narathiwat province in extreme southern Thailand (Chan-ard et al 2015.) Known prey includes frogs, lizards, and mammals. Here, we report the first record of predation by *T. nebularis* upon a member of the *Erinaceidae* family - *Hylomys suillus.*

At 2040 h on 18 August 2018, we encountered a recently deceased adult female *T. nebularis* (SVL = 672 mm, total length = 820 mm) (Fig. 1) laying amongst vegetation on the verge of a forest trail close to the town of Tanah Rata in the Cameron Highlands, Peninsular Malaysia (4.463576°N 101.387935°E; WGS 84, 1415 m elev). The cause of death was unknown; however, no visible recent injuries were present. Mucous covering the snake's anterior half suggests that it may have been partially consumed and regurgitated by another snake. A large prey item was noticeable within the deceased snake; dissection revealed an adult *Hylomys suillus* (short-tailed moon rat) measuring 132 mm total length. *Trimeresurus nebularis* is known to feed on small mammals, though to the best of our knowledge this

Figure 1: *Hylomys suillus* retrieved from the stomach of a deceased *Trimeresurus nebularis.*

observation is the first record of *T. nebularis* predating upon *H. suillus*. We would like to thank Evan Quah for his assistance with identifying the prey item.

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Inverting the Food Web: The Predation of an Adult Colubrid Snake, *Sibynophis triangularis,* by the Scorpion *Heterometrus laoticus* in the Sakaerat Biosphere Reserve

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Abstract:

The predation of vertebrates by large tropical invertebrates is a rare phenomenon in nature, though not unprecedented. Scorpions in particular are evolutionarily equipped to take on such a task. Despite the hunting strategy and primarily insectivorous diet of scorpions, they are known to opportunistically prey upon small vertebrate prey such as lizards, frogs and birds. Herein, we describe the observation of an adult Asian forest scorpion (*Heterometrus laoticus*; Scorpiones; Scorpionidae) predating upon an adult triangle many-toothed snake (*Sibynophis triangularis*; Squamata: Colubridae). Although the opportunistic predation on snakes by scorpions has been documented, we believe this to be the first record of the genus *Heterometrus* predating on a snake. Furthermore, we also believe this to be the largest documented prey snake in terms of total length for any scorpion species. This observation may have implications on subsequent studies looking at predator-prey interactions within habitats suitable for both small colubrid snakes and large invertebrate species.

Keywords: Scorpionidae, Colubridae, Thailand, prey, trophic cascade

Introduction:

The interactions between vertebrates and invertebrates, particularly within the trophic system they occupy, is a well-researched and understood topic (Belovsky & Slade 1993; Murkin & Batt 1987; Nordberg *et al.* 2018). This particularly pertains to the predation of invertebrates by larger vertebrate predators. However, there are far fewer instances of invertebrates consuming vertebrate prey items within the available literature. Scorpions are primarily fossorial ambush predators, emerging from their burrows and lying in wait at the entrance for unsuspecting prey to wander too close (Williams 1987). Scorpions typically exhibit an insectivorous diet, with the exception of a few species (Williams 1987), and have been known to Prey on frogs, birds, lizards and even snakes (McCormick & Polis, 1982). The genus *Heterometrus* is made up of large-bodied scorpions that phenotypically exhibit large powerful chelae, giving them the evolutionary tools to subdue vertebrate prey (Durale & Vyas 1968). We encountered the following observation of an Asian forest scorpion, *Heterometrus laoticus* (Scorpiones: Scorpionidae), during such an attempt.

Observation:

At 10:04am on the 26 September 2018, we came across the active predation attempt of a triangle many-toothed snake (*Sibynophis triangularis*; Squamata: Colubridae) by a large Asian forest scorpion (*Heterometrus laoticus*). The observation took place within the Sakaerat Biosphere Reserve (SBR) in northeast Thailand at 14.4589°N, 101.8867°E. The snake was observed first and only after a few moments did we see the scorpion which had a secure

Figure 1, *Heterometrus laoticus* capturing *Sibynophis triangularis* in the Sakaerat Biosphere Reserve, Thailand (Photo: Everett Madsen).

grip on the snake (Figure 1). We estimate the scorpion to be approximately 110 – 130mm in total length (TL) and the snake to be between 550-650mm TL.

The scorpion was gripping the snake with both chelae at the midbody, periodically adjusting its grip one chela at a time, while pulling small pieces of flesh off the dorsolateral region of the snake with its chelicerae (Figure 2). The snake was alive and alert but was unable to resist the predation; there was also blood visible where the scorpion had gripped the snake. We departed the area at 10:21am. At 11:41am, we returned to find the scorpion and snake in the same location and the scorpion still had the snake secured at the midbody with its chelae. At 11:50am the scorpion began dragging the snake into a nearby burrow likely due to the disturbance of the observers. The scorpion entered the burrow and subsequently pulled the snake into the retreat site until only a small portion of the snake could be seen. We then departed a second and final time at 11:52am.

Discussion:

Identification of the species involved was done following the observation using photo and video documentation made at the site. Among the three species of the snake genus *Sibynophis* that occur in Thailand (Cox *et al*. 2012), we concluded the prey item to be *S. triangularis* due to the black triangular nuchal spot bordered laterally by a cream stripe extending to the labials, a vertebral row of small black spots anteriorly becoming white more caudally, and its whitish ventral surface with small black spots on the edges of the ventrals and subcaudals (Cox *et al.* 2012; Chan-Ard *et al*. 2015, Chiaccio *et al*. 2017). Amongst the four species of *Heterometrus* scorpions found in

Thailand, we determined ours to be *H. laoticus* based off its smooth carapace without granules, and its smooth manus of the pedipalp with apparent punctae (Kovařík 2004).

We have described the active predation attempt and part of the subsequent consumption of a large vertebrate prey item by *H. laoticus* in northeast Thailand. While known to occasionally prey on vertebrates, they are generally small and rarely consist of snakes; with no documented vertebrate prey greater than 200 mm in total length (McCormick & Polis, 1982). This snake, at an estimated 550-650 mm TL, is larger than any other documented vertebrate prey of scorpions. Morphologically, *H. laoticus* is highly adapted to such an occurrence exhibiting large, powerful chelae enabling it to take advantage of small snake species as prey (Gwee 1996). The long, slender bodies of even moderately sized colubrid snakes are likely easily grasped and held in place by *H. laoticus* individuals (Lilywhite 2014). Additionally, species of the genus *Sibynophis* may be particularly vulnerable as their thin, comb-like teeth are likely ineffective against the scorpions thick chitinous exoskeleton (Zaher *et al*. 2012).

Figure 2, *Heterometrus laoticus* actively predating on *Sibyonophis triangularis* (Photo: Everett Madsen).

A poorly documented species, only a few specimens of *S. triangularis* have been discovered within the SBR, however this is the second documented instance of this species falling prey to a large invertebrate predator. Chiaccio *et al* (2017), discovered an individual being preyed upon by a centipede from the genus *Scolopendra*. These observations were opportunistic and further research, using *S. triangularis* as a focal species, is needed to gauge the prevalence of such events.

Sibynophis triangularis is thought to consume primarily skinks and other insectivorous squamates (geckos, blind snakes, etc.) (Mohapatra 2010). *Heterometrus* predation upon snakes such as *S. triangularis*, if frequent, could be removing an important pressure from those insectivore populations. The unprecedented size of the prey snake in this observation indicates that invertebrate predation on vertebrates may be more common than previously thought; with vertebrates at substantial sizes remaining susceptible to predation by large invertebrate predators such as *H. laoticus*. Interestingly, by predating on *S. triangularis*, the scorpion may be reducing the pressure on other insectivorous taxa in the area. A high density of other insectivores may reduce prey density through trophic cascading and result in an increase in direct competition between *H. laoticus* and the insectivores *S. triangularis* typically preys upon (Sih *et al*. 1998). However, as Finke (2005) showed, complex trophic interactions with multiple intraguild predators do not always yield predictable results. Intraguild predation between *H. laoticus*, *S. triangularis* and other species may add complexity to the food web, stabilizing and dampening the effects of any single predator on the ecosystem due to the antagonistic effects of different predator prey interactions (Finke 2004). Further studies aimed at understanding this and similar interactions could attempt to quantify and better understand these effects.

Acknowledgements:

We would like to thank the staff and director of the Sakaerat Environmental Research Station whom have allowed us to base our field work out of. Furthermore, we would like to thank the Wildlife Reserve Singapore group for sponsoring the work conducted in the biosphere reserve allowing us to continuously provide internship opportunities to national and international individuals.

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The Northern Cat-eyed Snake *Leptodeira septentrionalis* (Squamata; Colubridae): Hunting and Feeding Strategy on Red-eyed Tree Frog *Agalychnis callidryas* (Anura: Hylidae) in Belize

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The Northern Cat-eyed Snake *Leptodeira septentrionalis* is a rear-fanged colubrid distributed widely across Meso-America (Kohler, 2003), including the country of Belize (Platt et al. 2016). Opistoglyphous species like *L. septentrionalis* will bite and hold their prey, or sometimes chew to increase venom delivery, until their venom takes affects (Savage, 2002; Solórzano, 2004). These snakes generally swallow prey headfirst but have previously been documented using alternative feeding strategies, such as internal organ ingestion (Arroyo-Trejos & Mora, 2016). Tree frogs and their eggs are common in the diet of *L. septentrionalis* (Platt et al. 2016), and individuals often gather to feed during breeding aggregations (Solórzano, 2004; Wells, 2007). Research suggests anurans are the dietary staple of *L. septentrionalis,* and at least eight different prey species have been documented to date (e.g. Duellman, 1963; Cabrera-Guzmán et al., 2009; Dehling, 2009; Arias et al., 2015; Engeman and Engeman, 2015); including *Agalychnis callidryas* eggs (Duellman, 1958; Pyburn, 1963; Wells, 2007) and adults (Platt et al. 2016). The following note supports prior literature by providing another example of *A. callidryas* predation by *L. septentrionalis*. This event is notable as the snake was observed and photographed locating its prey using olfactory senses, before capturing and ingesting it from behind.
The observation took place on 28 August 2018, 19:50h at Lower Dover Field Station, Unitedville, Belize (GPS: N 17.21540°, W 0.88.94758°, 58m asl). While exploring this area of privately protected lowland rainforest, a small breeding aggregation of Red-eyed Treefrog *A. callidryas* and Veined Treefrog *Trachycephalus venulosus* were located by their repeated calling. Upon approaching and observing c. <15 *A. callidryas* individuals call among each other (some already in amplexus), an adult *L. septentrionalis* was located actively foraging on a dried palm frond adjacent to one prior-calling male individual. When the snake was c. <30cm from the frog, it raised its head and proceeded to sense its prey using the tongue in a series of slow flicks (Fig. 1A). Upon orientating the position of its prey, the snake tentatively approached while slowly flicking its tongue, before striking at a near touching distance. The snake grasped the frog from behind and began chewing the prey to deliver its venom and establish a better grip (Fig. 1B). A struggle ensued for c. 5 minutes, where *A. callidryas* attempted to prise itself free from capture using its rear feet. The frog's last line of defence was clinging firmly to its perch in a desperate tussle to keep hold (Fig. 1C), but within a few minutes *A. callidryas* succumbed to the snakes venom and its grip began to fail. After forcedly levering its prey free, *L. septentrionalis* proceeded to ingest the frog backwards without complication in little over 5 minutes (Fig. 1D).

Revisits to the site on the following two evenings located likely the same adult *L. septentrionalis* active again on the same palm leaf amid the group of breeding *A. callidryas*. No further predatory interactions were observed and no morphological data was collected.

Snakes are the main predators of anurans in habitats surrounding bodies of water (Wells, 2007; Santos-Silva et al., 2014). Given the accrual of frogs in the diet of *L.septentrionalis,* this snake could be a steadfast regulator of certain anuran populations in its range. The present observation indicates that *L.septentrionalis* not only locate their prey by movement but do also detect and stalk prey using olfactory senses. Following the suggestion of Arroyo-Trejos & Mora (2016), encounters of *L. septentrionalis* active on subsequent nights after feeding support the notion that this primitive colubrid predates prey 'little and often' as appose to 'large and infrequently' (Green, 1983). In summary, this note reaffirms the strong association of *L. septentrionalis* as predators at aggregation sites of breeding anurans like *A. callidryas.*

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I would like to wholeheartedly thank the owners Madeline, Bill and Justin Reynolds of Lower Dover Field Station, for their continued hospitality and support during short visits to explore the incredible biodiversity of Belize.

Figure 1. Photographs depicting the predation event from start to finish. **A: 19:52h** - *Leptodeira septentrionalis* approaching a Red-eyed Treefrog (*A. callidryas*) using its olfactory senses and tongue flicks. **B**: **19:55h** - *L. septentrionalis* strikes at the individual from behind and proceeds to chew and envenom its prey. **C**: **19:58h** - *L. septentrionalis* begins to ingest and prise the enervated *A. callidryas* from its perch. **D**: **20:04h** - Ingestion nears completion and only the front feet of *A. callidryas* remain protruding. © Tom W. Brown

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Predation of Bay-breasted Warbler *Setophaga castanea* (Parulidae) by Green Vinesnake *Oxybelis fulgidus* (Colubridae) on Utila Island, Honduras

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Introduction:

Oxybelis fulgidus (Daudin, 1803) known as the Green Vinesnake, is a well-camouflaged and arboreal colubrid with a wide spanning Neotropical range including most of Central America (Köhler, 2008; McCranie, 2011). These large but slender diurnal snakes are inept ambush predators, relying largely on their flawless leafy camouflage to stalk and acquire prey items. The diet of *O. fulgidus* includes a wide variety of lizards and songbirds (Passeriformes) (Scartozzoni et al., 2009), whereas mammals, frogs and insects are taken rarely or on occasion (Savage, 2002; Kohler, 2008). The venom of *O. fulgidus* is stored in high volumes, containing Fulgimotoxin, a specialist monomeric three-finger toxin (3FTxs) that is highly neurotoxic to lizards and birds, but of no effect on mammals (Heyborne & Mackessy, 2013).

Field observations on *O. fulgidus* throughout its Mesoamerican range have documented a wide variety of birds in its diet, that include seventeen families to date e.g. Bucconidae (Endo et al., 2007); Columbidae (Fraga et al., 2012; Miranda et al., 2013); Dendrocolaptidae (Scartozzoni et al., 2009; Fraga et al., 2012); Emberizidae (Sosa-Bartuano & Rodríguez-Beitía, 2015); Fringillidae (Scartozzoni et al., 2009; Fraga et al., 2012); Furnariidae (Leenders & Colwell, 2004; Díaz-Gamboa et al., 2017); Icteridae (Capurucho & Costa, 2012); Momotidae (Cherry, Jr. et al. 2017); Muscicapidae (Scartozzoni et al., 2009); Parulidae (Henderson & Binder, 1980; Henderson, 1982); Pipridae (Martins & Oliveira, 1998); Rallidae (Bringsøe, 2002); Thamnophilidae (Silva Pena et al., 2017); Thraupidae (Scartozzoni et al., 2009; Fraga et al., 2012; von May et al., 2018; Hernández-Ruz, 2019; Sánchez-Ojeda & Cortés-Suárez, 2019); Trochilidae (Van Dort, 2011); Turdidae (Figueroa & Valerio, 2011; Viana et al., 2014; Rodríguez-Pérez & Mata-Silva, 2019); and Tyraniidae (Hayes, 2002; Rodrigues et al., 2005; Viana et al., 2014). This observation provides the first published example of Bay-breasted Warbler *Setophaga castanea* predation by *O. fulgidus*, and perhaps the fourth ever reported instance of the family Parulidae (Warbler) in the diet of this snake (Henderson & Binder, 1980; Henderson, 1982; Scartozzoni et al., 2009).

Field Observation:

The observation commenced on 01 May 2019 at 15:30 h (+ 6hrs to GMT) on the grounds of Kanahau Utila Research & Conservation Facility, Utila Island, Honduras (16.119383° N, 86.884989° W, WGS 84). The authors attention was drawn by the squawking alarm call of a male *S. castanea* that was apparently 'mobbing' a snake it had encountered whilst foraging. Upon pinpointing the distressed bird c. 8 m high in the canopy of a broad-leaf tree,

Figure 1: (A & B) An adult Green Vinesnake (Oxybelis fulgidus) in the process of ingesting a Bay Breasted Warbler (*Setophaga castanea*) on Utila Island, Honduras. © Tom W. Brown

the author observed an adult *O. fulgidus* (c. 1300 mm Total Length) striking and firmly grasping the individual *S. castanea* by the head. The captured *S. castanea* struggled and flapped in an attempt to break free, but became limp and unresponsive after 10 m of being restrained (Fig 1a & b). After the *S. castanea* apparent demise, the adult *O. fulgidus* retracted and continued to hold the prey for c. 25 m, before beginning to maneuver and swallow the *S. castanea* in a headfirst position. Ingestion of the prey took >45 m in total, but was not observed for its entirety to avoid disturbance. The prey's identification was confirmed by photographs, as a male *S. castanea* has distinctive reddish brown upper flanks and two conspicuous wing bars (Gallardo, 2014).

Concluding Remarks:

While native birds are a common prey source for *O. fulgidus* throughout its range, this observation, on Utila Island, is especially notable as *S. castanea* has a migratory island status. Utila is an important albeit little studied site for migrating birds (Gallardo, 2014). An estimation of at least 70 - 90 different bird species may stop-off and overwinter on the island, of which c. 16 are reportedly small warblers (Sullivan et al., 2009). The greatest number of these species arrive in Honduras during the southern migration between October and April (Gallardo, 2014). This seasonal influx of migratory birds may provide a passing abundance of prey for *O. fulgidus,* influencing dietary shifts and changes in this snakes foraging strategy throughout the year. Previously, the only known examples of *O. fulgidus* diet on Utila included the lizards *Ctenosaura similis*, *Hemidactylus frenatus* (Brown et al., 2019) and *Basciliscus vittatus* (Brown, T. pers.observ.), as well as a small mouse (Köhler 2008) and the fatal ingestion attempt of a small bat *Saccopteryx leptura* (Brown et al., 2019[2]). This note attests to the varied diet of *O. fulgidus* by further documenting an avian prey item on Utila.

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Review on nonvenomous marine serpentes: Little file sea snake *Acrochordus granulatus* (Schneider, 1799), with an observation on bycatch composition from India

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Abstract:

The snake family Acrochordidae (non-venomous) includes the single genus, *Acrochordus*. All three *Acrochordus* species are aquatic snakes and confined to tropical oceans inhabiting coastal ecosystems of the Indo-Australian region. The three extant *Acrochordus* species exhibit strikingly different ecology, scalation, internal anatomy, and osteology. They have some of the most functional morphology and physiology for life in the aquatic environment compared to terrestrial and amphibious species viz sea kraits. *Acrochordus granulatus* is the most widely distributed species. There is little information recognized about the factors influencing the spatial and temporal stability of this specie's population. The species is commonly caught as bycatch in India that could lead to significant mortality. However, there is no data on status assessments of these snakes available. Long-term monitoring of populations is essential to evaluate the success of the persistence of marine snakes. This paper aims to compile the existing information on diversity, biology, and ecology of *A. granulatus*. Also, it highlights the threats to the sea snakes in general including the impact of pollution on the coastal and marine environment.

Key words: Coastal ecosystem, Threats, Conservation, Ecology, Human-snake negative interaction

Introduction:

Reptiles play an essential role in ecological processes. However, reptiles' roles in ecosystems, especially those inhabiting coastal areas are undervalued (De Miranda, 2017). Sea snakes are confined to the warm tropical waters of the Indian Ocean and western Pacific Ocean (Stidworthy, 1974). They mostly occupy coral reefs, intertidal areas and muddy beaches (Venkataraman *et al.*, 2012). Several adaptations have permitted sea snakes to accommodate to the marine environment (Damotharan *et al.*, 2010). The marine adaptations include swimming, respiration, salt excretion, marine fouling and skin shedding (Heatwole, 1999). They also have developed an oar like tail that further enhances their locomotion in water. A posterior sublingual gland under their tongue concentrates and excretes excess salt water from their body (Greene, 1997). Sea snakes shed their skin more often than land snakes, to remove fouling organisms like barnacles (Heatwole, 1999; Cogger, 2000; Karleskint *et al.*, 2012). Sea snakes play a crucial trophic role in near-shore marine ecosystems as predators (Venkatraman *et al.*, 2012). They are protected in India under the Indian Wildlife Protection Act, 1972 - Schedule IV (Whitaker *et al.*, 2004). Though they are ubiquitous, detailed information on these snakes lacks in India.

Family: Acrochordidae:

The family Acrochordidae (file snakes), consists of three extant species distributed over the tropical regions of the eastern Indian Ocean and the western Pacific (Ng, 2011). They are the Arafura file snake (*Acrochordus arafurae*), the Elephant trunk snake (*Acrochordus javanicus*) and the Little file snake (*Acrochordus granulatus*). The Little file snake is the smallest member of family Achrochordidae. All three living species of the Acrochordidae use a combination of aquatic environments ranging from freshwater to seawater and have been living in coastal habitats since 90.7 million years (Vidal *et al*., 2009).

***Acrochordus* species account:**

The three extant *Acrochordus* species displays noticeable difference in ecology, scalation, internal anatomy and osteology (McDowell, 1979). The head is covered with small granular scales; nostrils in annular nasals are rimmed, closely set and no cephalic scutes (Deraniyagala, 1995). The color pattern of the body exhibits alternate rings of dark brown and buff broadest on the side while narrow on the top, which become sub-equal at mid-body (Deraniyagala, 1995). The skull of *Acrochordus* characterized by the absence of a crista circumfenestralis (asynapomorphy) shared by all three species of *Acrochordus* (Rieppel and Zaher, 2001). Eco-toxicological studies revealed heavy metals such as aluminum, cromium, copper, iron, mercury, manganese, lead, strontium, zinc found in nine *A. javanicus* from the Indomalayan and Australian zone (Grillitsch and Schiesari, 2010). *Acrochordus granulatus* occupy a unique phylogenetic position (See Williams *et al*., 2006; Pyron *et al*., 2013; Zheng and Wiens, 2016). *Acrochordus* species diverged in the Miocene epoch i.e., between 16 and 20 million years ago (Sanders *et al*., 2010). *Acrochordus granulatus* (Schneider, 1799) previously classified in a separate monotypic genus (Chersydrus; Sanders *et al*., 2010). Sanders *et al.* (2010) provided the first phylogeny for the three extant species using Bayesian and parsimony analyses of one mitochondrial and two nuclear gene sequences.

***Acrochordus granulatus* – Morphology and Distribution:**

Unlike other marine snakes of Hydrophiinae sub-family, *A. granulatus* bear thin and slender tails like terrestrial snakes (See Figure 1b). They usually reach a maximum length of about 90-120 cm (SVL; Rao and Muralidharan, 2017) and show sexual dimorphism; females are larger than males (Wangkulangkul *et al*., 2005). The size at maturation in both sexes is 58 cm (SVL) in Thailand (Wangkulangkul, 2004). Distribution of *A. granulatus* is reported in China, Australia, Indonesia, Bangladesh, India, Malaysia, Myanmar, Philippine Islands, Singapore, Sri Lanka, Thailand, Vietnam and Australia North coast (Voris and Glodek, 1980). Also, this species is distributed in all marine coasts of India from Gujarat to West Bengal, Andaman and Nicobar Islands. The coasts of Gujarat are probably its western most limits (Murthy, 1986; Harikrishnan *et al*., 2010). They typically inhabit streams, lagoons and other areas of permanent fresh water estuaries and occasionally enter the sea (Lilywhite, 1996). Further, it is found to be active in shallow water, no deeper than 20 meters (Wall, 1921). This species can be seen in coastal wetlands and estuaries of Sri Lanka (Deraniyagala, 1995).

Physiology:

Acrochordus granulatus require fresh water and will drink it periodically when living in a range of salinities from seawater to fresh water (Lillywhite, 1996). Further, it has a higher relative blood volume (% body mass) than other snakes, since they have more red blood cells which help to carry more oxygen (Feder, 1980). They have some of the most specialized morphology and physiology for life in saltwater compared to other marine reptiles, including the greatest capacity to store oxygen found in any vertebrate (Heatwole, 1999). This snake is capable of exceptionally prolonged submergence; maximum submergence time averaged 70% longer than in other marine snakes (Feder, 1980). In *A. granulatus* blood parameters such as plasma lipids, plasma cholesterol, plasma proteins and serum calcium greatly increased during the breeding period (*i.e.* during late December to early January); come to basal level and remain normal throughout the nonbreeding period (*i.e.* during late January to early November in India; Phadke and Padgaonkar, 2003). Rise in these blood parameters is due to the secretion of the ovarian estrogen, since only steroids are able to bring about such effect (Phadke and Padgaonkar, 2003). The parathyroid gland of the snake, *A. granulatus*, secretes a parathormone-like factor (Warbhuwan and Padgaonkar, 1996). The expected plasma changes associated with vitellogenesis in the annual ovarian cycle (Phadke and Padgaonkar, 2003).

Acrochordus granulatus are sensitive to low temperatures and rapid thermal changes (Lilywhite, 1996). *A. granulatus* is usually a nocturnal species, during the day it hides inside burrows in mud or among rooted vegetation (Lilywhite, 1996). Additionally, each scale contains a mechanoreceptor that may be used to locate fish in turbid water (Povel and Kooij, 1996). The diving and metabolic physiology of this species is highly specialized and reflects the demands of estuarine environments. A capability for prolonged aerobic diving can be attributed to low rates of oxygen consumption, high capacity for oxygen storage, nearly complete utilization of the oxygen stores, and cutaneous gas exchange (Lilywhite and Tamir, 1994). This species is primarily ammonotelic and requires a source of fresh water for elimination of nitrogenous wastes (Lilywhite, 1996). The requirement for fresh water potentially limits seaward migration due to the dependence of snakes on rivers or coastal rainfall. Adaptations for shallow-water diving conceivably further limits seaward migration, with the result that they have evolved as

Figure 1a, File sea snake *Acrochordus granulatus* caught as bycatch in Amba estuary, Maharashtra, India

Figure 1b, File sea snake *Acrochordus granulaus* caught as bycatch in Amba estuary, Maharashtra, India estuarine specialists that are restricted from deeper waters and the open ocean (Lilywhite and Tamir, 1994).

Trophic Ecology:

Unlike other sea snakes *i.e.* elapids, *A. granulatus* are non-venomous and feed on crustaceans and gobid fish, which are abundant in estuaries (Ng, 2011). In *A. arafurae* females ambush prey in deep water while males actively search for prey in shallow water (Vincent *et al*., 2005). Further, *A*. *granulatus* show low feeding frequencies and prolonged gestation in adult females (Bergmann, 1958; Gorman *et al*., 1981).

Reproduction:

Reportedly, the breeding season of this species in Phang Nga Bay, Thailand begins in July (Padate *et al*., 2009). Their reproduction is seasonal, being ovo-viviparous, directly giving birth up to five young individuals (Voris and Glodek, 1980; Shine and Houston, 1993). They are capable of breeding in freshwater (Waterwatch, 2002).

Threats:

One of the important destructive activities is by-catch of sea snakes during trawl nets, which could lead to significant mortality (Lobo, 2007). Sea snakes captured in a trawl operation are prevented from surfacing to breathe. This is coupled with several other factors such as depth, fishing crafts such as trawl and gill nets in the trawling operation result in their mortality (Lobo, 2006). Some gravid female sea snakes die due to stress of being trapped in fishing nets (Rao and Muralidharan, 2017). The level of mortality of sea snakes within trawls also depends on the depth of the trawl, weight and size of the catch (Milton, *et al*., 2009). Pelagic and coastal marine habitats suffer from intensive and destructive fishing and land-use practices that potentially threaten sea snakes (Heatwole, 1997; Wassenberg, *et al.,* 2001). Sea snakes are susceptible to high mortality from trawling and are at risk of extinction (Milton *et al*., 2009).

Bycatch Records:

Of the 30 sea snakes found along the Indian coast, there are 18 species that are frequently caught as bycatch, *A. granulatus* is one among them (Lobo *et al.,* 2004, 2005; Lobo, 2006; Karthikeyan and Balasubramanian, 2007; Padate *et al*., 2009; Muthukumaran, 2015; Jeyabaskaran, 2015; Venkatraman, *et al*., 2015). The effects of the exploitation or by catch on the sea snakes are almost unknown except limited information is available from the Philippines and Australia (Ward, 2000; Wassenberg *et al*., 2001; Heales *et al*., 2008). Trawling in the Amba estuary is difficult and risky due to uneven sub tidal topography. Experimental trawling was carried out at four stations in Amba estuary (18^0 45’ N & 73^0 10’ E) during low and high tides for five consecutive days in pre and post monsoon in 2014 from the mouth of the estuary along the creeks of Amba estuary, India. Bottom trawling was undertaken wherever possible using a high opening bottom net of 20.7 m (636 meshes of 50 mm) length. Trawl net of mesh size 1 – 1.5 inch was used to catch fish.

During experimental trawling *A. granulatus* was caught (Figure. 1a,b) in Amba estuary (18^0 45’ 16.3” N 72^0 59’ 11.4” E). The snake was non-offensive and released back to the estuary immediately. The length of the snake was about one meter and the snake was undergoing dysecdysis (See Figure. 1 a, b). Lilywhite, (1996) reported that *A. granulatus* unusual shedding behaviour in captivity by knotting. Earlier bycatch incidence was reported during trawling in Ratnagiri in December 2013 (Swapnil, *pers. comm.*). Recently, Rao and Muralidharan (2017) reported *A. granulatus* bycatch in Malvan during trawling in January 2017. Reportedly the snake was lethargic and fishermen usually handle them routinely, they are typically reluctant to bite when handled, even when injured (Wall, 1921; Ng, 2011; Stuebing *et al.,* 2014).

Bycatch Prevention:

Most of sea snakes caught as by-catch are discarded. To reduce bycatch related mortalities exclusion devices has been used for sea turtle (Werner *et al*., 2017). The same management strategies, such as the use of excluder devices with spatial closure in trawl nets can be designed and implemented to avoid incidental capture of sea snakes in the trawl nets (Udyawer, 2015),

Conservation:

In general, sea snakes are exploited for their meat, skin and internal organs in many parts of the world and are sometimes internationally traded (Heatwole, 1997). However, they are not currently protected under (CITES) Convention on International Trade in Endangered Species of Wild Fauna and Flora (IUCN, 2009). Detailed information on Sea snake's biology and natural history is not available and they are impacted by a number of human activities, including harvesting for food, leather (Heatwole, 1997), incidental mortality in fishing operations (Milton 2009; Courtney *et al*., 2010) and degradation of coastal habitats (Bonnet *et al.,* 2009). Sea snakes are also threatened by the damming of rivers, construction of barrages, fishing pressure, pollution and dredging activity (Naidu *et al*., 2016). Commonly caught by-catch sea snakes exploited for skin and used for the pet trade in western countries, and in Philipines *A. granulatus* is hunted for its skin, where it is used as leather and to make drums (Buddy and Kay, 2006; Smith, 1943). Currently, sea snakes are caught and commercially traded in Gulf of Thailand (Nguyen *et al*., 2014). Although, *A. granulatus* are considered as Least Concerned category in IUCN (2009) red list, this species listed as nationally threatened in Sri Lanka (Kekulandala and Wickramasinghe, 2006; IUCN Sri Lanka, 2000).

The incidental, unintentional take of non-commercial and non-target species in fishing gear has been an ever-increasing threat to the marine life and considered one of the major threats to marine biodiversity. Incidental capture and consequential removal of predators such as sea snakes by commercial fishing operations could have negative impacts on the functioning of marine ecosystems (Lobo, 2006). This leads to commonly encountered by-catch in fishing operations (Lobo *et al*., 2004).

Heavy metals such as Mercury, are being circulated in a marine food chain due to various natural and anthropogenic activities. Further, requisite action is needed in order to control the anthropogenic activities that are responsible for Polycyclic Aromatic Hydrocarbons and metal contamination in the coastal environment. Reptiles living in polluted habitats also accumulate trace elements, which are expelled when the skin is sloughed (Loumbourdis, 1997; Campbell and Campbell, 2001; Hopkins *et al*., 2001; Jones and Holladay, 2006**)**, concentrations of trace elements were higher in snakes from urban-industrial areas and higher in darker than paler skin (Goiran *et al.,* 2017). The effect of pollution and survival rate after getting entangled in fishing on the distribution and abundance of *A. granulatus* is unknown and thus merit for further evaluation.

Conclusion:

Information on the movement, dispersal and ecological association with other organisms of *A. granulatus* is lacking. Less information is available about the physiological tolerance in marine environment. Understanding major distribution and essential microhabitats of these species can help to minimize the encounter of the bycatch problem**.** Gathering information on breeding cycles, bycatch mortality, growth rates, population density and sexual maturity would help in formulating management plans. We aim to develop awareness programs for better understanding of cumulative impacts affecting on sea snakes in inshore habitat. In addition, an education campaign should be designed to educate fishermen on the general biology, potential dangers and species identification of sea snakes in general, that would help to reduce the negative interaction of sea snake in its distribution area and the setting up of proper treatment facilities in the event of casualties could help to save human lives.

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