Preliminary notes on *Varanus exanthematicus* during the reproductive season in the coastal plain of Ghana

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Abstract
An eleven day study of *Varanus exanthematicus* conducted in November and December 2016 collected data on the thermal environment, condition, behaviour, abundance and excavations of the lizards in grasslands around Dawa, in the coastal plain of Ghana. Pairs of animals were found mating or in close proximity to each other and gravid females were observed digging what appeared to be nesting holes. Based on one researcher's experience of the species from over 30 years of collecting animals for wildlife trade we identified, mapped and categorised burrows of the species as nesting burrows (dug exclusively by females) or shelter burrows (dug by either sex). Basic characteristics of burrows were recorded and measured. None of the nesting burrows excavated contained *Varanus* eggs except one which contained a single hatched eggshell. These burrows may represent abortive, exploratory or decoy nesting sites. Mating females had dry white deposits over the dorsal surface of the pelvis and hind legs, a condition apparently not previously observed in *Varanus* of any species except captive *V. albigularis microstictus*. Some males were dripping seminal fluid when captured and all males had prominent patches of what appeared to be a waxy secretion on the soles of the hind feet which covered 10-15 scales and were absent in females. These structures have also been noted in *V. albigularis microstictus*. The results are discussed in the context of extremely low survival rates of exported female *V. exanthematicus* in captivity.

Introduction

Varanus exanthematicus, known colloquially by animal collectors as “*bok*” and in the Nungu languge spoken at Dawa as “*piti*”, is an important species in live animal trade from West Africa, with almost 900,000 specimens exported since 1975 (CITES trade statistics derived from the CITES Trade Database, UNEP World Conservation Monitoring Centre, Cambridge, UK). Despite substantial improvements in husbandry techniques for *Varanus* lizards which have resulted in regular captive reproduction for some species, *V. exanthematicus* still performs very poorly in captivity. Documented breeding events are isolated and very rarely repeated, and cycling of females in any captive environment appears to be rare and never occurs for longer than a couple of years. Nesting in captive females is extremely rare, with most reproductive females depositing eggs on the surface. The only information about the biology and natural history of the species are studies of diet and reproductive cycles in Senegal (Cisse 1971, 1972, 1976) and a study of abundance, diet and feeding ecology of mainly juvenile animals (<six months) in the coastal plain of Ghana conducted during the wet season months March to August (summarised in Bennett 2004). The lack of information about the nesting ecology of *V. exanthematicus* prompted this short study which was funded entirely by amateur keepers of the animals.

Study area and dates

Two sites chosen for the study were Kogyae Strict Nature Reserve, Ashanti Region, and Dawa, Greater Accra Region, Ghana (Figure 1). The team consisted of both authors (hereafter DB and BA) and a member of local wildlife staff (at Kogyae only). One day was spent one day around Kogyae Reserve Headquarters on December 1st 2016. At Dawa, exploratory surveys were conducted 19-20th November, and searches for animals between 22-28th November and 2-5 December 2016. The site was revisted (by BA) on 11th January 2017 for an observational assessment.

The area at Dawa searched comprised about 14km^2 of heavily modified coastal savannah north of the Accra - Afiao road around Dawa, Ghana (Figures 2 & 36). The area is a mosaic of active and fallow farmlands, and uncultivated areas of grass land with small patches of bushes and trees. Cattle grazing is common in uncultivated areas. Nearly all farms in the area grew peppers, very few fields contained watermelon, foxtail (“red”) millet and cassava.

Methodology

Suitable habitat was searched for lizards and signs of lizards between about 8am and 4pm most days. Animal caught were examined, weighed with digital kitchen scales (Hanson, China), measured with a flexible steel ruler (tail base circumference, body circumference, snout-vent length and tail length), marked with a unique set of notches (Figure 30) and released at point of capture, sometimes with 1-4 cocoon bobbins (Figure 13) of polyester thread (Danfield, UK, type Nm 120/2, 10W, Beige 42) attached to the tail using either Duck Tape (ShurTech, USA) or a generic duct tape (Tesco UK). Sex was determined based on eversion of hemipenes in males and overall appearance of females (narrower tail base, no eversion, relatively stout bodies, narrower more pointed snout).

Thread trails were followed at least 24 hours after release and attempts made to map animals' movements based on trails. The positions of spool devices found that had detached from lizards were mapped.

Two pairs of animal were examined that had been caught by a local hunter. One pair had been killed. The alimentary tracts of these animals were removed and other body parts and internal organs weighed and returned to the hunter. The other pair were measured, marked and released with cocoon bobbins taped to the tails in the area where the hunter indicated he had caught them on the following morning.

Burrows thought to have been used by the lizards (based on previous experience of researchers) were mapped and some excavated. For excavated burrows at least maximum depth, length and width of the tunnel complex was recorded. Burrows were classified as shelter burrows or nest type burrows based on previous experience of researchers.

Surface temperatures were taken in and out of shade at intervals throughout the study period with a simple infa red thermometer (IR Micro, China), together with skin surface temperatures (ventral and dorsal) of captured lizards (where this could be taken within 30 seconds of capture), temperatures at burrow entrances and substrate temperatures where lizards were seen or captured.

Fecal samples were collected from animals during handling or recovered whilst following thread trails. Feces were rinsed and identifiable fragments noted. Two alimentary tracts obtained from a hunter were weighed and contents noted.

The potential use of camera traps in the study of the species was investigated by deploying a single camera trap (Bushnell Trophy 119436, China) set to take 3 pictures 1 second apart with a 60 second delay at two sites within the study area for periods of 5-7 days. Sites chosen were thickets where lizards had been caught previously.

Results

Individuals

Nine or 10 individual adult *V. exanthematicus* were seen during searches and all were caught except two females excavating nesting burrows. Two individuals were captured twice. All were found on the ground, usually under bushes or low vegetation. One female was found with its tail sticking out of a burrow in an exposed area, where it was apparently digging up crickets. Another female who appeared heavily gravid was found on open sand close to an area where we had found two females in nest holes earlier that day, and may have been one of those animals. Two pairs were observed mating and another pair were found within 5m of each other in a thicket. The animals caught twice were a male of approx 275mm SVL, 1.20kg, caught on 23rd November and 5th December, and a female 350mm SVL, 1.05kg, caught on 24th November in close proximity to one male and on 3rd December when it was mating with another male. Four animals (2:2) caught by a local hunter encountered within the study site on 3rd December were also examined. A pair caught in the morning had been bludgeoned to death, the other pair had been caught in the afternoon and appeared uninjured. Overall sex ratio of animals examined was 1:1. Location of animals seen is given in Figure 3. Measurements of animals examined are summarised in Table 1 and Figure 4.

Burrows

The locations of 52 shelter and nest type burrows were recorded (Figures 5& 6) and all 13 nest type burrows were completely or partially excavated. Characteristics of nest type burrows are given in Table 2 and sketches of burrows in Appendix 2. No nest type burrows contained eggs except a single old eggshell that appeared to have hatched successfully. Another contained hatched chameleon eggshells.

Temperatures

Substrate temperatures recorded are depicted in Table 3 and Figure 7. On days with little cloud cover unshaded surface temperatures reached 40^{o}C by about 10am and remained above 40^{o}C until around 3pm. Under shade surface temperatures increased more slowly, peaking between 1 and 4pm and rarely exceeding 35^{o}C. Mean burrow entrance surface temperatures were 37.2^{o}C ($\pm$5.5, n=27) and nest holes entrance surface temperatures were 35.7^{o}C ($\pm$2.9, n=5).

Skin temperatures of eight lizards ranged from 32-36.1^{o}C. Dorsal surfaces were slightly warmer than ventral surfaces, but not significantly so (Table 4).

Diet

Two lower alimentary tracts of dead animals and eight fecal samples contained orthopteran parts. One fecal sample also contained many small hairs that might represent an insect larva. The stomach contents of the male weighed 41g (3.2% of body mass) and comprised 1 adult and 7 subadult locusts, 14 crickets, a grasshopper (Acridae) and an adult preying mantis (Figures 7 & 8). Stomach contents of the female weighed 31g (4% of body mass) and comprised 6 locusts and 11 black crickets (Figure 9). Total alimentary tract contents accounted for 8% of body mass of the female and 6% of the male.

Physical condition

All animals caught appeared in good condition. All had ticks situated mainly around the vent, head and insertion of the limbs. All males examined had very obvious dark secretions on scales just proximal to the 1st toe on the underneath of the hind feet, which were lacking in females (Figures 10 & 11). Two females that were mating when found had dried white deposits all over the dorsal surface of the pelvic region and hind legs (Figures 12 & 13). Several of the males caught appeared to be discharging seminal fluid from either side of the vent, which could be differentiated from the milky-white fluid extruded with feces (Figure 14). One animal had extensive scarring on the flank and tail that might have resulted from a predation attempt by *V. niloticus*, judging from teeth marks visible in the tail. None of the males had scratches on the dorsum associated with bipedal male combat reported in many *Varanus* species. One male had a swollen foot that might have been from a recent fight.

Camera Trap

The camera trap recorded three sets of images of *V. exanthematicus* at a single site over five days (11:30 on 27th November until 11:30 on 2nd December 2016). The site was in a thicket containing a large rock, with a burrow underneath, which a female (35cm SVL, 1050g) lizard had entered after being released with spool and line device on 24th November. All pictures appear to be of the same individual. The animal was recorded on November 28th at 08:48 and appeared to be investigating the camera (Figures 15-17). It was recorded again on 1st December between 12:14 and 12:22 around the hole, in a vertical position against the rock and walking away from the rock with its tongue flicking (figure 18-21). A Duiker, bird and large rodent were also recorded at the same site (Figures 22-24). No images were recorded at the second site. On December 4th the lizard that entered the hole was recaptured, this time mating with a male 303m from the original capture site.

Spool and line tracking

Six animals were fitted with spool and line devices on seven occasions and were followed 32-584m (mean 242 $\pm$ 188, Figure 29). One two occasions devices fixed with Duck tape detached less than 40m from release point. Thread trails were followed until the devices detached from the lizard (3) or time constraints prevented further searching (4).

#16 37cm SVL male (Figure 25)
One spool. Duck tape. Moved 208m through three bushes and foraged around the last bush – lost the thread, abandoned.

#22 35cm male (Figure 26).
Two spools, Duck tape. Moved 331m, 2g of thread left in spool. Visited a burrow but didn't go inside. Changed direction and headed more or less directly to a large thorn thicket moving from bush to bush and defecating on the way. Avoided open areas and farmland. Spool fell off in thorn thicket,

#33 35cm female – followed twice (Figures 26 & 27).
24th November. One spool, Duck tape. Fell off after 32m
3rd December One spool, duct tape. Dropped off after 243m.The animal circled a termite mound just before the spool fell off.

#43 36cm male (Figure 27)
Four spools, duct tape. Travelled 584m, visited area regularly occupied by female he was mating with, abandoned. Spool found 260m from release point 336m from end of thread, two days after release. Spool was next to a burrow and a recent *Naja* shed.

#23 33cm female
One spool, Duck tape. Dropped off 38m from release point. Thread trail broken in several places, took a long time to find – abandoned, not mapped.

#14 34cm male (Figure 28)
Two spools, duct tape. Moved 256m in and out of fields. Abandoned.

Kogyae Strict Game Reserve
No signs of *V. exanthematicus* were found in a five hour search around the headquarters. The wildlife officer who accompanied the search had been at the park for 15 years and had never seen the species. He had heard that the animal ate beans (a common belief among farmers who see them hunting insects). None of the wildlife staff present at headquarters could suggest areas where the species occurred except one who said they occurred around her home village. Because of the limited time available and uncertainty of finding animals we opted to return to Dawa for the remainder of the project.

Discussion

The timing of this study aimed to coincide with the egg laying season of *V. exanthematicus*, which, according to wildlife trappers interviewed in Ghana between 1994 and 2001, occurs in November and December. Although we found heavily gravid females and mating pairs we did not find any nests. Assuming a three week period between mating and oviposition, the egg laying season probably peaks in later December and may not be finished before traditional farm burning after Christmas. A local pig farmer said he saw *V. exanthematicus* mating close to his farm in late October 2016. His description could have been of mating or combat behaviour and suggests that the reproductive season extends over at least three months. A visit to the site on January 10th 2017 found that the area had been burned according to traditional farming patterns. Adults were seen in trees and likely to be entering a period of fasting and relative inactivity that will last until some weeks (possibly months) after the hatchlings have emerged in March or April. During this period the adults (but not the offspring from the previous year) are often observed resting on *Elaeophorbia drupifera* trees, and appear very emaciated by March/April (based on visits by DB and BA in 2001). Visits by BA and the late Wahabo Belu between 2002 and 2010 suggest that adults are highly clustered on *Elaeophorbia* trees during the dry season and in the past have been collected from the area in large numbers.

Specimens of *V. exanthematicus* found during this study were larger and warmer than those we have encountered at other times of year, and probably represent sexually mature animals at peak activity. Overall the numbers of lizards encountered (12 captures in approx 78 hours of searching = 0.15 per hour) was much lower than at other times of the year. At good sites in previous years experienced hunters found an average of 0.43 ± 0.28 adults per hour between March and August (Bennett 2004). Low encounter rate might be due to clustering of males around females and possibly females clustering around nesting areas, Southern areas of the site contained much evidence of lizards but yielded very few specimens (see Figure 2).

The minimum size of sexually mature females given by Cisse (1976) is 500g and the smallest found previously in Ghana was a 27cm SVL animal with enlarged follicles that weighed 350g in August (Bennett 2004). The smallest male and female found in this study were 34 and 27cm SVL which is probably about the minimum size at sexual maturity for this population.

All animals examined appeared to have been feeding, and the stomach contents examined indicate that both males and females conduct extensive foraging at this time of year. As has been reported for populations in Senegal (Cisse 1972), diet towards the end of the wet season was composed almost entirely of orthopterans. Both dissected animals contained many intact prey, suggesting that they had eaten the morning they were killed. Values for total predator mass prey ratios may be underestimated because the animals had been bludgeoned to death and probably lost most of the lower gut contents in the process.

All the specimens caught during this study were found on the ground, despite searches that also included likely trees. In March and April the animals in this area are found in trees, looking very emaciated an apparently not feeding. The tree used most regularly is *Eleaophorbia*, which has very stout branches and highly toxic latex sap known to cause extensive eye damage.

Despite being weeks away from an extended fast the two dissected animals did not contain large fat bodies (3% of body mass for both sexes). This is in accordance with fat body sizes in Senegal (Cisse *et al.*1976b) which reached a maximum of 4% prior to onset of the dry season fast. The fat cycle of the species in Senegal suggests that most fat is accumulated over a few weeks immediately before the onset of inactivity (from mean of 0.8% of body mass in October to 4% in December) and metabolised through the dry season (falling to 1% of body mass by June). Smaller accumulations of fat in July (around 2% of body mass) are metabolised by October when the reproductive season peaks in Senegal and when fat levels are lowest (mean of 0.8% of body mass). In Ghana the period between reproduction and the onset of dry season is much shorter and fat reserves during reproduction are probably used through the dry season. Cisse *et al.* did not distinguish between the sexes of animals in their sample, so any differences in fat storage and use between sexes during the reproductive season remain unknown.

Small yolked follicles in the dissected female were about 20% of the mass of a fully developed shelled clutch, and available body fat reserves alone were probably sufficient for this transformation (Cisse et al. 1976b). Cursory inspection of the oviduct did not reveal a banding pattern indicative of recent oviposition as described by Auffenberg (1994) for *V. bengalensis*. However the oviduct did appear distended and it is possible that the animal had produced a clutch of eggs in the recent past.

In this study test nest burrows are defined as burrows that are dug by females looking for suitable places to deposit eggs. They differ from burrows used by either sex as regular shelters in their position (always located under direct sun and usually on exposed, slightly elevated fallow fields with very low and sparse vegetation) and in the appearance of the entrances which appear lower than regular burrows (see Figures 31-32). They were identified based on previous experience by BA who has over 30 years experience of catching the animals, mainly for supply to animal exporters. Nest burrows consist basically of a bent tunnel with an egg chamber created off the main shaft. Very fine silt is used to cover the eggs and coarser material to refill the burrow lumen. The entrance is smoothed over and the nests only become easy to find after hatchlings have begun to emerge from the nest via a small hole on the surface which leads directly from the nest chamber and does not follow the burrow lumen. Lizard egg shells should persist in the environment for a long time and the very small numbers of *Varanus* and *Chamaeleo* eggs we excavated are unlikely to constitute entire clutches and probably indicate abortive nesting behaviour in the past. It seems probable that many more test nest burrows are dug than are actually used for oviposition, and that burrows may be utilised over more than one year (based on signs of recent occupation in a burrow containing a hatched egg shell. Multiple nest burrows might reflect females' search for a suitable nesting environment and/or be a strategy for deterring predators (see Stanner 2004 for discussion of nest hole use by *V. griseus*). Figure 38 shows a plan of a burrow containing 15 eggs found in the coastal plain of Ghana in April 1996. The neonates had dug an escape shaft directly to the surface.

Test nesting burrows appear to be clustered on particular fallow field sites. We found one extensive test nesting burrow in a pile of sand that had been dumped by the road (Figures 34/34a). Substrates at fallow field sites absorb more solar radiation than areas with taller plants and more shade, and may be less prone to damage from fire because of scant vegetation.

Females found in the final hours of fieldwork appeared ready to lay eggs. One was digging a burrow in a fallow field site when discovered by farmers (Figure 32), another had recently excavated a chamber and had its head nearest the burrow entrance and looked as if it was about to lay eggs (Figure 31). Both animals appear to have been disturbed by our investigations and abandoned the sites, at least temporarily. A female found in the same area on the same day appeared heavily gravid and reluctant to move (Figure 33).

The origin of the dry white deposits on mating females cannot be determined but are certainly left by another lizard. The positioning of the deposits across the females' pelvis and hind legs suggests it occurs whilst the animals are clasped in copulation and might be consistent with observations of a wet track resulting from alternating copulation in this species (Ziegler and Bohme 1997, Plate XIV, Coiro 2007). The deposits found on both copulating females were completely dry, suggesting that they did not originate from the copulation observed. At least one pair of lizards had been mating for some time, judging from the cleared area where they had been lying (Figure 35). Several of the males caught appeared to be discharging a seminal fluid from either side of the vent, which could be differentiated from the urate rich, milky-white fluid extruded with feces (Figure 14). The deposits on females' backs could represent either or both of these fluids. Visible deposits left after mating have not been observed in other *Varanus* species where copulation apparently occurs without external fluid or deposits (according to at least 10 highly experienced *Varanus* breeders whose opinions were sought) but Andrew Llewellyn (personal communication) has observed it in large groups of *exanthematicus* exported together and also in young male *V. albigularis* and males after combat. He reports that *V. albigularis* drip seminal fluid the entire time a female is cycling in the building and that it smells as strong as feces, but of maple syrup. Similar observations of a maple syrup or roast almond smell from *V. albigularis* type animals have been noted by the late Mark Bayless and others (In litt.). Visible seminal fluid is also apparent in Figure 10 of Kiraly (2014).

All male animals in this study had dark patches of what appeared to be a waxy secretion that covered about 10-15 scales on the sole of the hind feet, just proximal to the first toe. In all females these scales were slightly discoloured but otherwise unremarkable. They appear to provide an unambiguous indication of sex in wild adult *V. exanthematicus*, at least during the mating season. Whether the patches appear seasonally is not known, but in captive *V. a. microstictus* they becomes callous like during the breeding season and then reduce to a discolouration (A. Llewellyn personal communication). These patches cannot be discerned in at least some species of *Euprepiosuarus* and *Varanus* subgenera monitor lizards (V. Weijola, D. Kischner, personal communications). Examination of the feet of captive male *V. exanthematicus* suggests that the patches do not develop in those animals until the animals are between two and three years old, and that males between 2 and 3 years old who have not developed the patches are known to mate with females, but may not produce fertile eggs (Liam Saville, personal communication).

A noteworthy feature of the thread trails left by *V. exanthematicus* is that they stay extremely close to the ground, never climbing anything and rarely passing over obstacles, preferring to go underneath or around instead. In a few places clear pathways through vegetation could be distinguished but on the whole the paths used by the lizards are too low to be visible to standing people. Most movement occurred under shade and through thickets of vegetation and animals tended to move directly from bush to bush. Most movement was essentially in straight lines and led to features (thickets, burrows and termite mounds) that might be important to the animals. The trail of #13/14 was unlike other lizards because the lizard made a loop, returned to point of release and made a similar excursion just a few metres further to the west before the search for the trail was abandoned due to time shortages. This animal had not been released at point of capture because it was rescued from a hunter who had caught it somewhere in the area on the previous day. It is probable that the shape of the trail signifies a lack of knowledge of the area where the animal was released.

Tracing thread trails at Dawa was complicated by the presence of cattle in the area and severely hampered by the use of a single colour of thread that closely matched the substrate. Thread trail were often fragmented and it was difficult, time consuming and frustrating to find broken thread trails. Consequently some attempts to map movement were abandoned before they were completed. Only one of the tracked animals entered a burrow, which might be attributable to short duration of attachment or some other factor. One animal made a very obvious approach to a burrow entrance but did not enter.

Spool and line tracking is very inexpensive and can provide a very detailed picture of movement over short periods of time. It has been demonstrated to work well on some medium and large monitor lizards and some snakes and amphibians (Thompson 1992, Bennett 2014, Law *et al.* 2016, Waddell *et al.* 2016). The method may not be particularly suitable for *V. exanthematicus* because it is a small bodied species (limiting the number of spools that can be attached) that can cover large distances (greater than thread length in one spool) per day. The only possible point of attachment for the devices on a *Varanus* lizard is the tail (Bennett 2014), which limits movement in that area and may affect behaviour, particularly the blocking of burrow lumens with the tail for protection against predators. It also seems certain that the devices would impair the ability of either sex to mate successfully. In the present study all the trails mapped appear to represent less than one day of activity (based on the absence of trails leading to refugia) and many spool devices (particularly those attached with Duck tape) appear to have detached from the lizards within minutes or hours of release. Attachment time can be increased by cleaning the tail with alcohol prior to device attachment, but in any case is unlikely to extend beyond a few days. Further trials of the methods are required to evaluate its potential for use in this habitat and to assess any differences in behaviour that spool and line devices might provoke.

Camera traps have been used previously to target large and very large monitor lizards (Arifiandy et al. 2013, Bennett & Clements 2014, Law *et al.* 2016) but their use in studies of smaller species has not been evaluated. Passive infrared triggers (PIR) used in proprietary camera traps depend on the target animal having a different surface temperature to the ambient temperature within the detection range, which cannot be assumed for lizards, and therefore an unknown proportion of events are likely to be missed by camera trapping. Missed events could be estimated using time lapse in conjunction with PIR camera traps. Camera traps, especially set in video mode, have the potential to be extremely informative in investigations into the natural history of this animal.

The closest relatives to *V. exanthematicus* are the *V. albigularis* group of southern Africa, of which the best studied population are *V. albigularis albigularis* of Etosha National Park, Namibia (Phillips 1995, 2004), animals around four times heavier than *V.exanthematicus*. Wet season diet is similar to that of *V.exanthematicus* (snails, millipedes, grasshoppers, beetles and crickets) but the animals also eat a lot of snakes (*Naja*, *Bitis* and *Psammophis*), ground nesting birds and their eggs. They did not eat mammals, despite often sharing underground refuges with ground squirrels. Activity was greatly reduced during the winter (cold dry season), as the result of scarcity of food rather than climatic conditions, and animals lost 4-5% of mass per month during the dry season with males ending dry season at 60% of their peak wet season mass and females losing 25-40% of mass through reproduction in the middle of the dry season to end the dry season at about 50% of peak wet season masses. The weight is recovered within two months of the start of the rainy season. *V. albigularis* spends time in trees particularly during the reproductive season (with receptive females “almost always” located in trees) and in the dry season when some individuals stayed in the same tree for months. Males moved 1-4km per day to find females, mated over a 1-2 day period and some mated with more than one female. Male-male interactions only occurred in the presence of estrus females. Egglaying occurred about five weeks after mating. Sex ratios of 1:1 were recorded along transects during the rainy season, rising to 6:1 in mating season because of the movement of males. Phillips and Packard (1994) report on four *V. albigularis* nests in Namibia three were in burrows made by ground squirrels, one was in decomposing leaf litter and hatched after 120 days, vs 135-150 days for eggs in burrows, attributed to a higher temperature. Hatch rate at these nests was only 47%, with many completing development but failing to hatch. Three nests they examined were 88-102cm deep, about twice as deep as four *V. exanthematicus* nests in Ghana which had 100% hatch rates (Bennett 2004). *V. exanthematicus* apparently store much less fat for dry season sustenance and have a much more restricted diet than *V. albigularis*, specialising in invertebrates and particularly on millipedes earlier in the wet season and orthopterans towards the end. There appears to be no arboreal element to mating behaviour in *V. exanthematicus*, and the animals appear entirely terrestrial at this time of year.

Observations from local people

Locally *V. exanthematicus* is known as "piti". It is not eaten by local people but some collect it for bushmeat trade. The hunter we met indicated that he expected to get 5 cedis for each lizard. He said that *V. niloticus* was easier to find than *V. exanthematicus*.

Kogyae Strict Nature Reserve

Musah *et al.* (2015) recorded *V. exanthematicus* as being present in savannah grasslands but absent from riparian forest areas at Kogyae, and that the species was regularly encountered "mostly on a weekly basis" according to interviews with inhabitants. The interviews were carried out at Congo and Dagomba (Y. Musah, personal communication). However the wildlife staff and farmers we met around the Reserve Headquarters were not acquainted with the animal and only seemed to know *V. niloticus*. The loamy soil around the Reserve Headquarters did not support burrows well and if the animals occur on such substrates they are likely to be sheltering on or above the ground. Evidently *V. exanthematicus* has a patchy distribution in the area that can most easily be determined by an interview question that requires knowledge of the differences between the well known *V. niloticus* (mampam or "woowaa in Dagbani language) and the relatively obscure *V. exanthematicus* ("yuggu"in Dagbani, "tantey" in Gonja).

Implications for captive husbandry

Virtually all the information on the how *V. exanthematicus* fares in captivity is anecdotal. Adult females appear to be rare in captivity, and those that show signs of cycling even more so. It is presumed that equal numbers of both sexes are imported and so the perceived rarity of adult females is probably an indication of early mortality. Juveniles are prone to desiccation, metabolic bone disease and infestation from internal parasites present at export. Reproductive issues were cited by Mendyk *et al.* (2013) as a major cause of mortality in female zoo maintained *Varanus* and it seems likely that this is the case for the captive population of *V. exanthematicus*.

For pet owners male *V. exanthematicus* are much more suitable than females. The harvesting of only male animals for wildlife trade would have less of an effect on the exploited population than the removal of females, and the animals would survive for longer in captivity. However sexes appear impossible to differentiate with certainty until maturity and no W microchromosome marker is known for the species (Matsubara *et al.* 2014) . Parthenogenic reproduction in many *Varanus* species results in all male offspring

(Grabbe & Koch 2014 and references therein), and if parthenogenic reproduction could be stimulated in *V. exanthematicus*, the resulting offspring could be guaranteed to be male and therefore of higher value than mixed sex animals. However there are some doubts about the viability and vigour of some parthengenically produced *Varanus* offspring, and the stimuli that trigger parthenogenic reproduction are not understood.

Male *V. exanthematicus* can do very well in captivity under a bewildering range of conditions, attaining lengths of over 1m in the first year of life and living for over a decade (although not necessarily the same individuals). In contrast females do very badly. There is anecdotal evidence that females grow more slowly and have a more reclusive disposition than males from an early age. Females in captivity that survive beyond the age of sexual maturity (perhaps at three years, possibly as young as 10 months) apparently do not cycle, or if they do, reabsorb eggs without complications. Lack of suitable nesting is certainly responsible for some mortality in female *V. exanthematicus*. This study suggests that most *V. exanthematicus* nests would fit within a block of substrate $1m^2$ and 50cm deep, and that surface temperatures of nests experience the full range of temperatures given in Figure 7. In their study of Namibian *V. albigularis* nests Phillips and Packard (1994) estimated that soil temperature 120cm below the surface was a more or less constant 27.7^{o}C. At 60cm deep soil temperatures ranged from 26-33^{o}C and at 20cm from 22-41^{o}C. Assuming similar patterns of soil heating and cooling, the nests of *V. exanthematicus* would experience fluctuations of around 7^{o}C. Further assuming that females' prefer a substrate temperature of 31^{o}C when nesting suggests that nest substrate should be as cool as 25^{o}C at the bottom, 31oC in the middle and heated to at least 35^{o}C at the surface. The water holding capacity of nesting substrates and the climatic conditions experienced by incubating eggs have not been investigated and warrant particular attention in the future

All known populations of *V. exanthematicus* undergo a period of low activity and fasting that commences with the onset of dry season (and shortly after the end of the reproductive season) and lasts for about six months. Biochemical and histological changes associated with seasonality are discussed in Cisse *et al.* 1975, Cisse & Demaille (1976), Cisse *et al.* 1976a,b, Cisse 1980, Dupe-Godet & Adjovi 1981a,b,c, Godet *et al.* 1984 who suggest total metabolic rest and "starvation" in a Senegalese population and major changes in fat metabolism, and glucagons, insulin, somatostatin and contents of pancreas. Cisse *et al.* 1976b suggested that stored fat was utilised for gonadal growth but did not differentiate between males and females in their study. Sustained reproductive cycling in captive populations of some *Varanus* species that undergo seasonal periods of inactivity is known (e.g. Good 1999), and a period of rest (specifically hibernation) documented as being essential for *V. griseus* (Perry *et al.* 1993). In captivity no attempts have been made to mimic this cycle with *V. exanthematicus*, and in the absence of lower temperatures animals constantly maintain higher metabolic rates, often with much higher levels of body fat than have been found in wild populations. *V. exanthematicus* are commonly obese in captivity, capable of acquiring 20% of their own body weight in fat within a few months (Gunther 1861), enough to theoretically sustain them through two and a half years of drought and starvation (Cisse *et al.* 1976b).

Wild *V. exanthematicus* punctuate days of very low activity with days of intense foraging, regularly walking at least hundreds of meters per day in search of food and probably not retiring until the stomach is full or the weather becomes unsuitable. They are one of the few monitor lizards that are known not to habitually prey on dead animals and appear to have a rather specialised diet. In captivity the provision of large, dead food items is convenient, but probably detrimental to the animals' overall activity levels. In the first few months of life *V. exanthematicus* eats small numbers of relatively large prey items, but as adults their diet consists largely of small prey which are evidently collected with great effort. Not allowing animals to hunt and forage for living, non vertebrate, prey deprives them of most of their habitual activity and contributes to obesity problems.

Very few of the people who keep *V. exanthematicus* have any interest in breeding them. The low market value of the animals makes them the least profitable of *Varanus* species to breed, and easy access to wild caught neonates make breeding the animals an unprofitable proposition. As has been the case with many other wild caught species popular in the pet trade, this situation will be completely reversed when captive bred colour morphs of the species are eventually produced. At present there is no evidence that established husbandry methods can result in regular captive reproduction in *V. exanthematicus*, and considerable evidence that the species performs very poorly in captivity overall.

Recommendations for future research

Aspects of the reproductive behaviour of *V. exanthematicus* are amenable to study using non destructive methodologies and more intensive studies of the species would unquestionably reveal unique features of its natural history. However they are unlikely to provide quantitative data on reproductive output. Data on the reproductive biology and fecundity of *V. exanthematicus* is almost entirely lacking and of direct relevance to the management of the species where it is economically exploited. Low survival rates in exported captive female *V. exanthematicus* are an increasing cause for concern among pet keepers, and the best husbandry advice available to keepers of the animals appears suitable only for males. Understanding of the animals' ecology and natural history should therefore be considered a priority despite its global IUCN listing of Least Concern (Bennett & Sweet 2010) and a regional assessment of the species is highly desirable.

V. exanthematicus remains an important component of wildlife export from Ghana, but sources of animals and export markets have changed drastically since early assessments conducted for Ghana Wildlife authorities between 1994 and 1997. Ghana now imports a considerable number of *V. exanthematicus* from Benin and Togo, mainly for re-export to new Asian markets and annual exports overall are substantially higher than they were twenty years ago. Ghana exports a much lower proportion of animals with declared sources of C, I or R, and a far higher proportion of wild caught animals, than other major exporters of *V. exanthematicus*, although this probably reflects more stringent attitude to monitoring on part of licensing authorities rather than a biological reality. There is no evidence of captive breeding of the species anywhere in the world, and despite the unusually high fecundity of both *V. exanthematicus* and *V. niloticus* no serious attempts to farm the animals has ever been undertaken, as far as I am aware. Declared sources of *Varanus* lizards from Indonesia are considered fabricated (Lyons & Natusch 2012) and de Buffrenil (1993) considered facilities he visited in West Africa to be unsustainable. At present there is no documented evidence of the existence of monitor lizard farms in any country where the animals occur naturally.

Discussion with some wildlife exporters in Ghana indicated that they would welcome improvements in husbandry techniques for *Varanus* lizards. Developing a successful protocol for establishing captive bred populations of the animals would have major benefits for wildlife traders and consumers. Therefore a project that combines investigations into wild populations with investigations into the captive biology of the animals would be highly desirable.

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Tables

		Mean	SD	Range	N
SVL (mm)	Males	363	23.0	340-400	6
	Females	328	33.9	270-375	7
Tail (mm)	Males	366	25.8	320-390	6
	Females	310	12.1	300-330	6
Mass (g)	Males	1256	143.4	507-1106	7
	Females	859	214.1	1094-1511	7
Tailbase circumference (mm)	Males	142	16.8	115-160	5
	Females	113	4.1	110-120	6
Body circumference (mm)	Males	225	22.1	195-252	5
	Females	227	22.7	200-265	6

Table 1. Measurements of *Varanus exanthematicus* caught at Dawa.

	Entrance width	Entrance height	Max depth	M 1	M2
Mean (cm)	10	8.6	53.7	105	77.6
sd	0.7	0.5	32.1	37.6	23.7
range	9-11	8-9	20-120	67-190	25-120
N	5	5	12	13	13

Table 2. Characteristics of empty nesting burrows. M1 & M2 are the total length and width of the excavation taken at surface level.

	Mean	SD	Range	N
In sun °C	38.4	7.2	24.7-60.3	223
In shade °C	33.4	3.1	25.4-41.5	79

Table 3. Summary of substrate temperatures taken at Dawa.

	Dorsal temperature	Ventral Temperature
Mean (°C)	34.9	34.8
SD	0.81	1.3
Range	34.1-36.1	32-35.8
N	8	8

Table 4. Skin temperatures of *V. exanthematicus* taken within 30 seconds of capture.

Sex	Male	Female	unit
SVL	35.5	34.5	cm
Tail	35.5	30.3	cm
Mass	1280	777	g
Reproductive organs	1.00	3.00	% of body mass
Alimentary tract (including contents)	11.00	14.00	% of body mass
Liver & heart	6.00	5.00	% of body mass
Kidneys	0.30		% of body mass
Fat	3.00	3.00	% of body mass
Head	7.00	9.00	% of body mass
Neck	5.00	6.00	% of body mass
Torso	25.00	23.00	% of body mass
Tail	17.00	13.00	% of body mass
Forelimbs	9.00	11.00	% of body mass
Hindlimbs	12.00	12.00	% of body mass

Table 5. Relative mass of body parts of *Varanus exanthematicus*

Figure 1. Study sites

Figure 2. Main study area with positions of all features recorded.

Figure 3. Distribution of *Varanus exanthematicus* seen at Dawa: males (green), females (yellow), pairs of animals (orange) and gravid females in nest burrows (red).

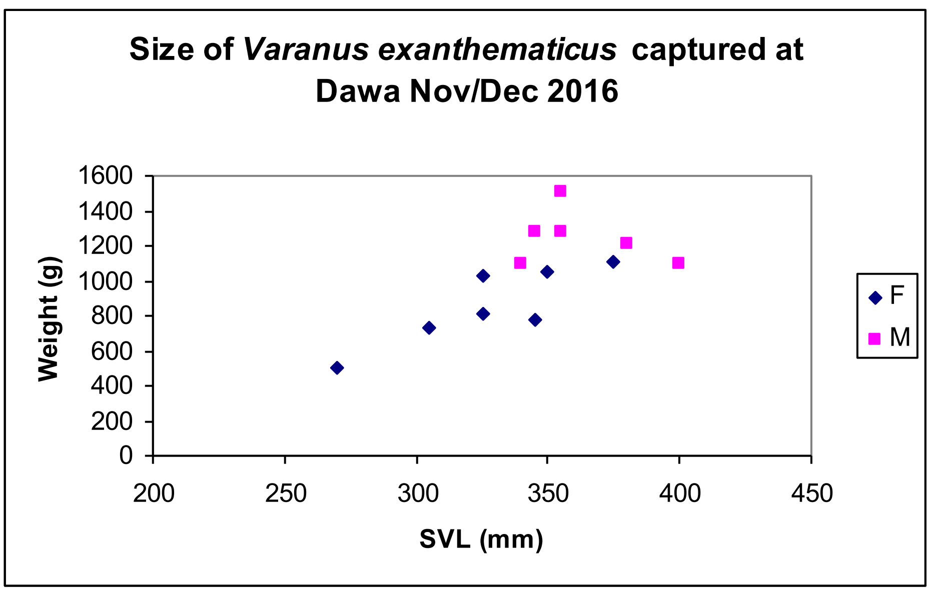


Figure 4. SVL vs. weight for both sexes of *V. exanthematicus*

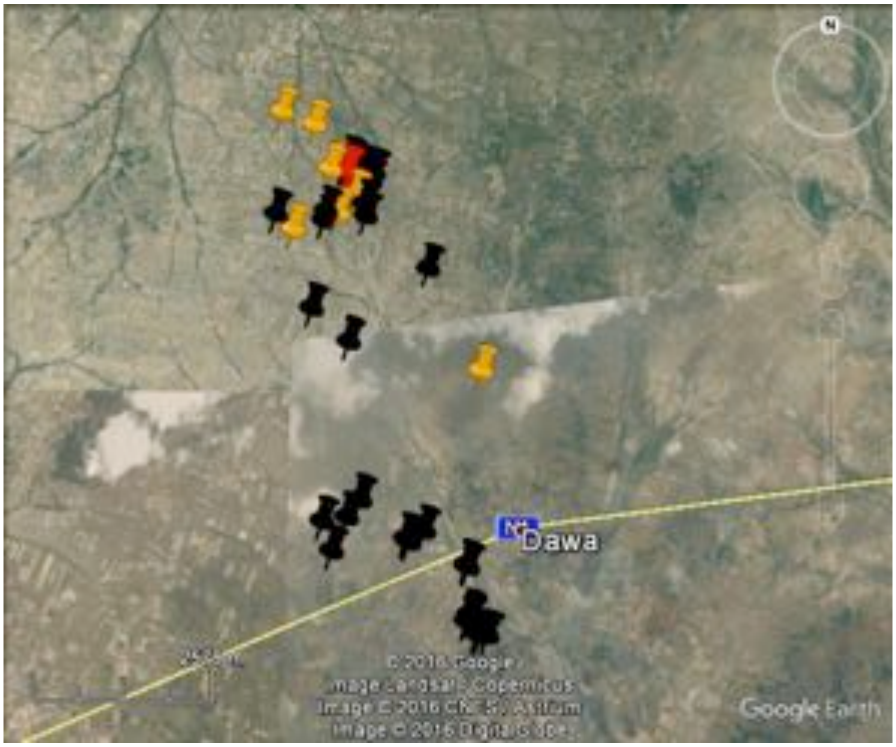


Figure 5. Distribution of *Varanus exanthematicus* burrows (black), empty nest burrows (orange) and nest burrows with gravid females inside (red) found November – December 2016.

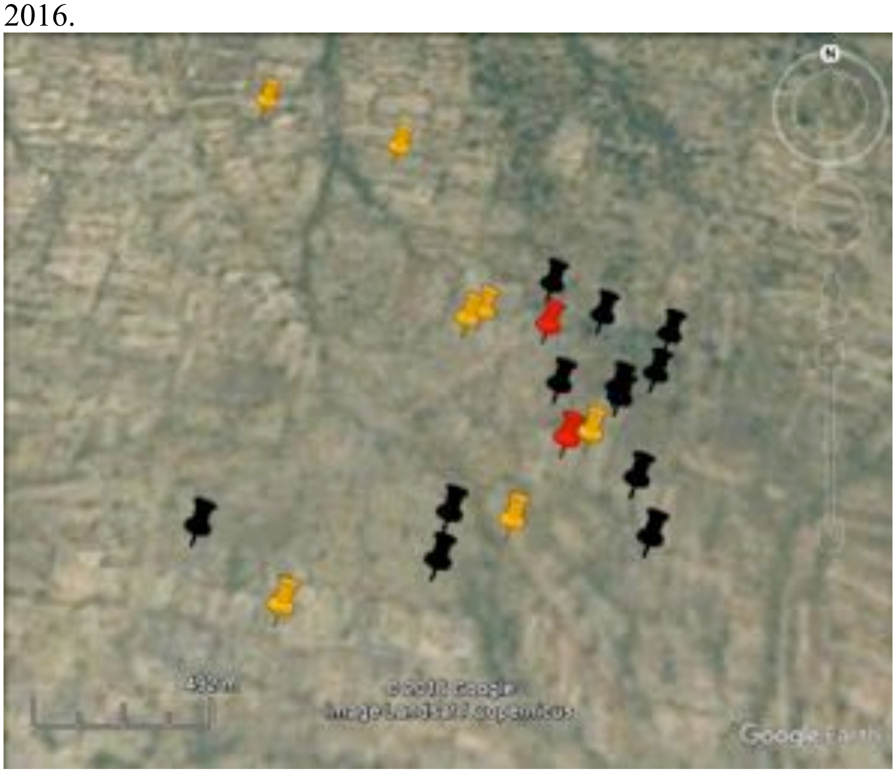


Figure 6. Distribution of *Varanus exanthematicus* burrows (black), empty nest burrows (orange) and nest burrows with gravid females inside (red) found in north of study site, November – December 2016.

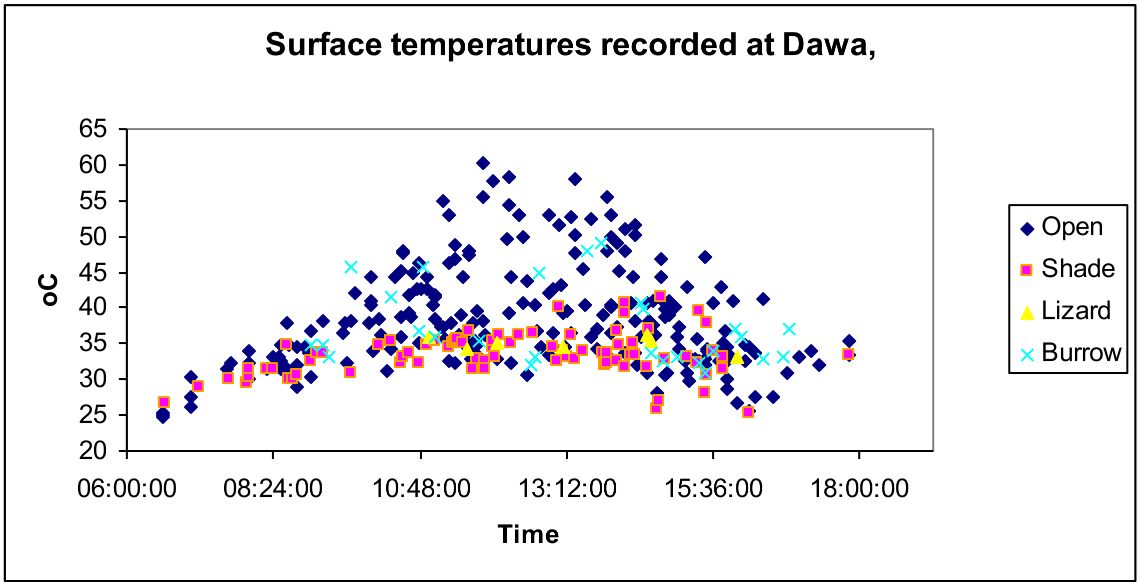


Figure 7. Surface temperatures of substrate and captured lizards

Figure 8. Stomach contents of male, 35.5 cm SVL (5mm squares)


Figure 9. Stomach contents of female 34.5 cm SVL (5mm squares).


Figure 10. Hind foot sole of male.


Figure 11. Hind foot sole of female.


Figure 12. Female #1 caught while mating.

Figure 13. Female #33, caught whilst mating.

Figure 14. Seminal fluid seepage in male *Varanus exanthematicus*

Figures 15. Camera trap image

Figure 16. Camera trap image.

Figure 17. Camera trap image.

Figure 18. Camera trap image.

Figure 19. Camera trap image.

Figure 20. Camera trap image.

Figure 21. Camera trap image.

Figure 22. Camera trap image.


Figure 23. Camera trap image.

Figure 24. Camera trap image.

Figure 25. Trail of #16

Figure 26. Trail of #33 (pink) and #22 (red)

Figure 27. Trail of #33 (light purple) and #43 (dark purple)

Figure 28. Trail of #14

Figure 29. All mapped trails

Figure 30. Tail notches to identify individuals - #22

Figure 31. Female *Varanus exanthematicus* encountered at nesting hole.

Figure 32. Female *Varanus exanthematicus* disturbed by farmers at nesting hole.

Figure 33. Heavily gravid *Varanus exanthematicus* found on open ground.

Figure 34. Nest type burrow in sand pile by road.

Figure 34a. Excavated nest type burrow in sand pile by road.


Figure 35. Cleared area used by mating *Varanus exanthematicus*


Figure 36. Typical habitat at Dawa.

Figure 37. Mummified *Chameleo senegalensis*.

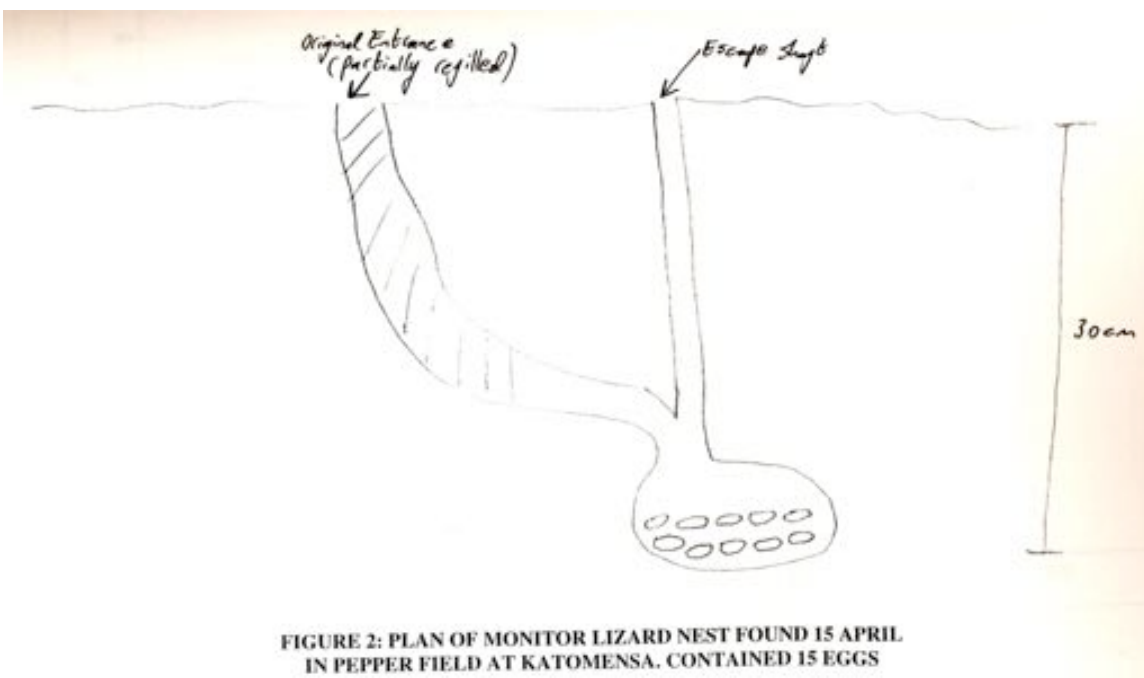
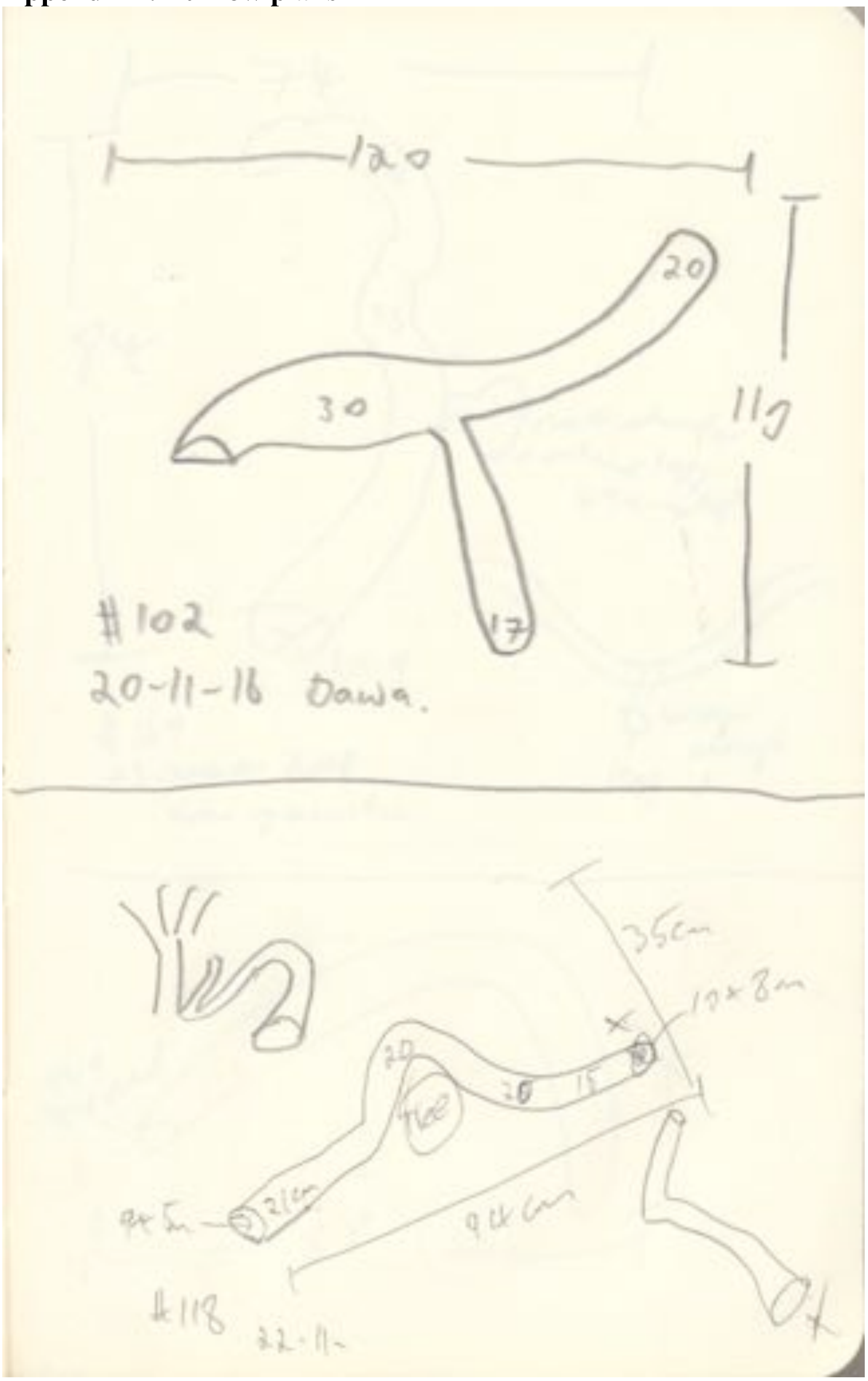


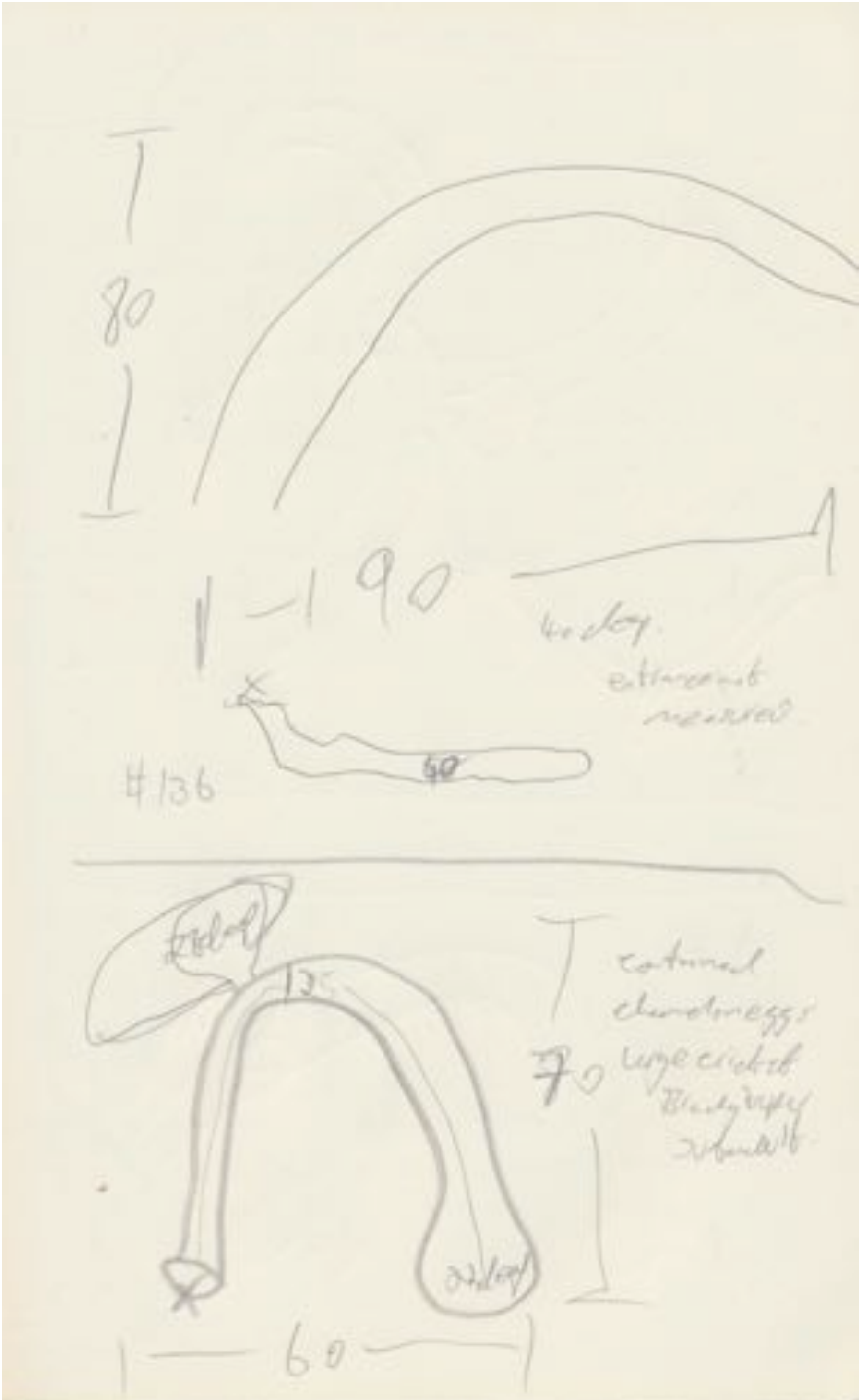
Figure 38. Plan of a burrow found Katamanso, 50km west of Dawa, April 1996. (from unpublished report).

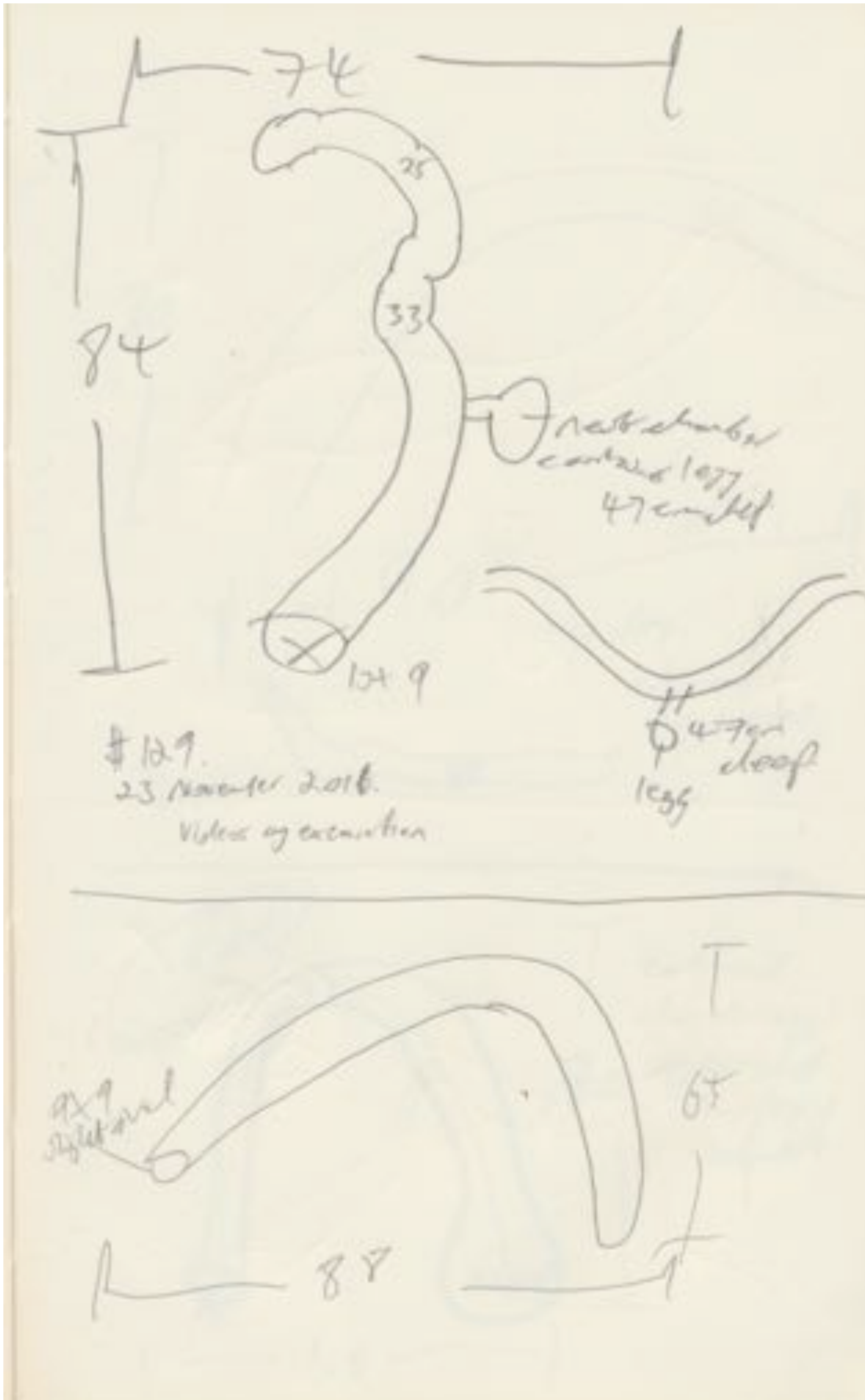
Appendix1 : Observations of other animals at Dawa.

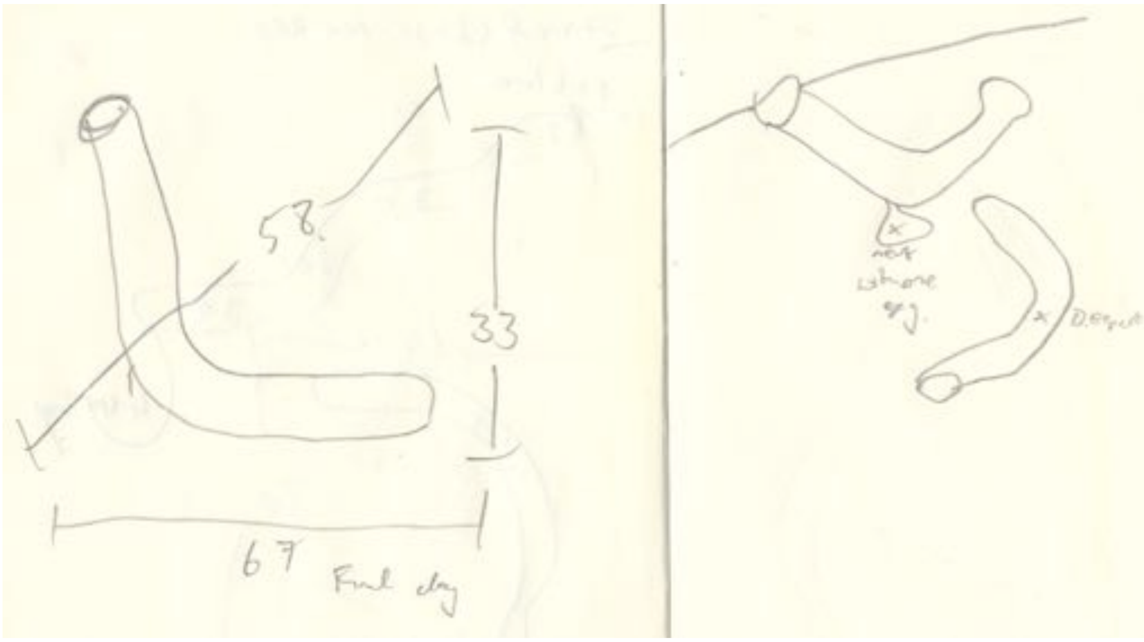
Burrows of rodents and *Brachytrupes* crickets are abundant in the area. On several occasions we found hedgehogs hidden in long grass or under piles of dead wood, once with a litter of youngsters. Francolin (*Peliperdix sp.*) eggs and spoor were regularly encountered. We found a single puff adder (*Bitis arietans*) under a pile of dead wood and saw a spitting cobra (*Naja nigricollis*) crossing the road. Two recent snake sheds were found: probably *Bothrophthalmus lineatus* which is known to wildlife collectors as "four line" and regarded as a major predator of *Varanus exanthematicus* and one spitting cobra. One of us (BA) has previously found green mamba *(Dendroaspis viridis*) along the river east of the study site and *Python* spp. in grasslands with high termite mounds to the NE of the study site. No direct evidence of *Varanus niloticus* was found at the study site but we found spoor likely to be from this species on two occasions, caught a subadult animal in the area previously (March/April 2001) and they are reported by local people to be common in nearby riverine habitat. On three occasions we saw footprints of tortoise (probably *Kininyx belliana* which is known from Shai Hills). We found the mummified corpse of a heavily gravid chameleon (*Chameleo senegalensis*, Figure 37) in a bush with a shallow (25cm) burrow at the base that contained hatched eggshells. The camera trap revealed the presence of a duiker in the area (Figure 23). We found no spoor of the animals during the project and presume they are locally rare.

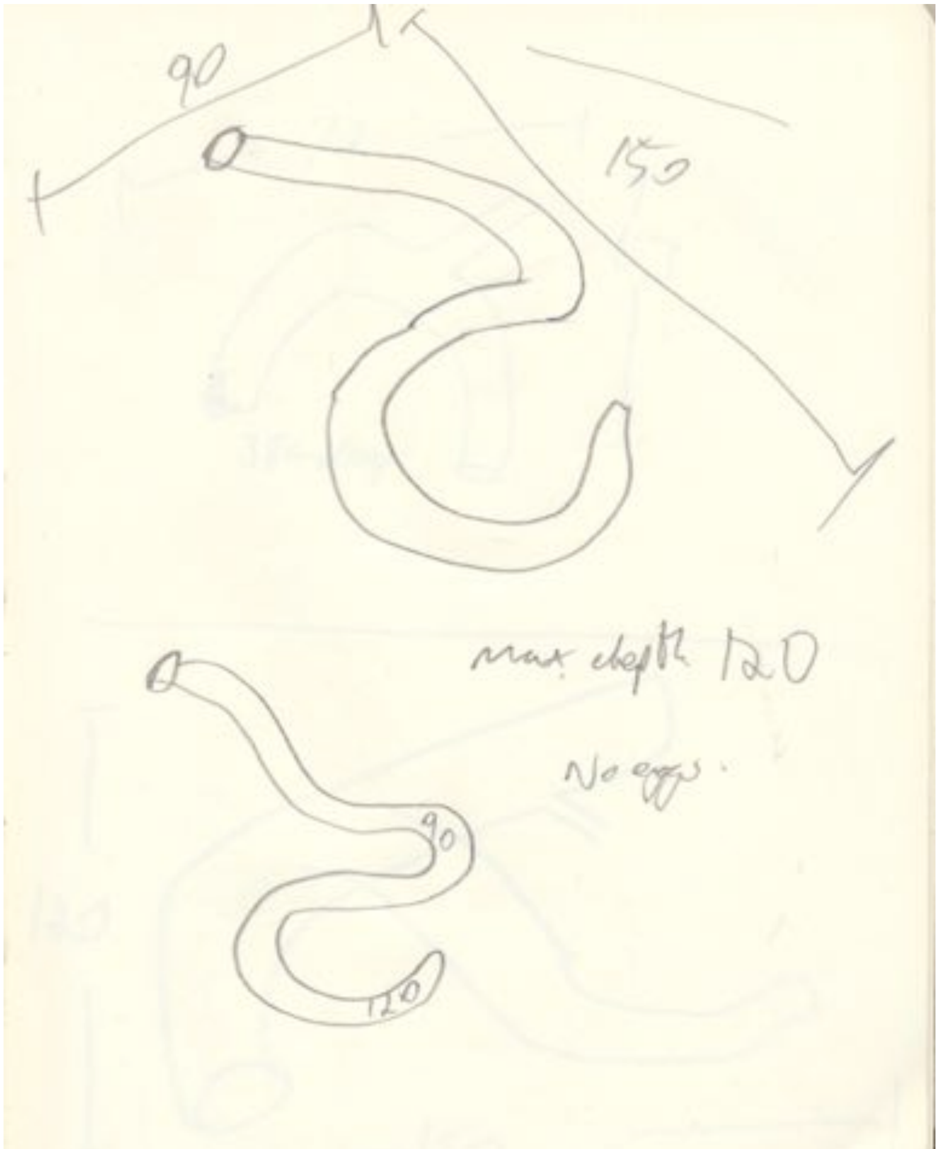
Appendix 2. Burrow plans

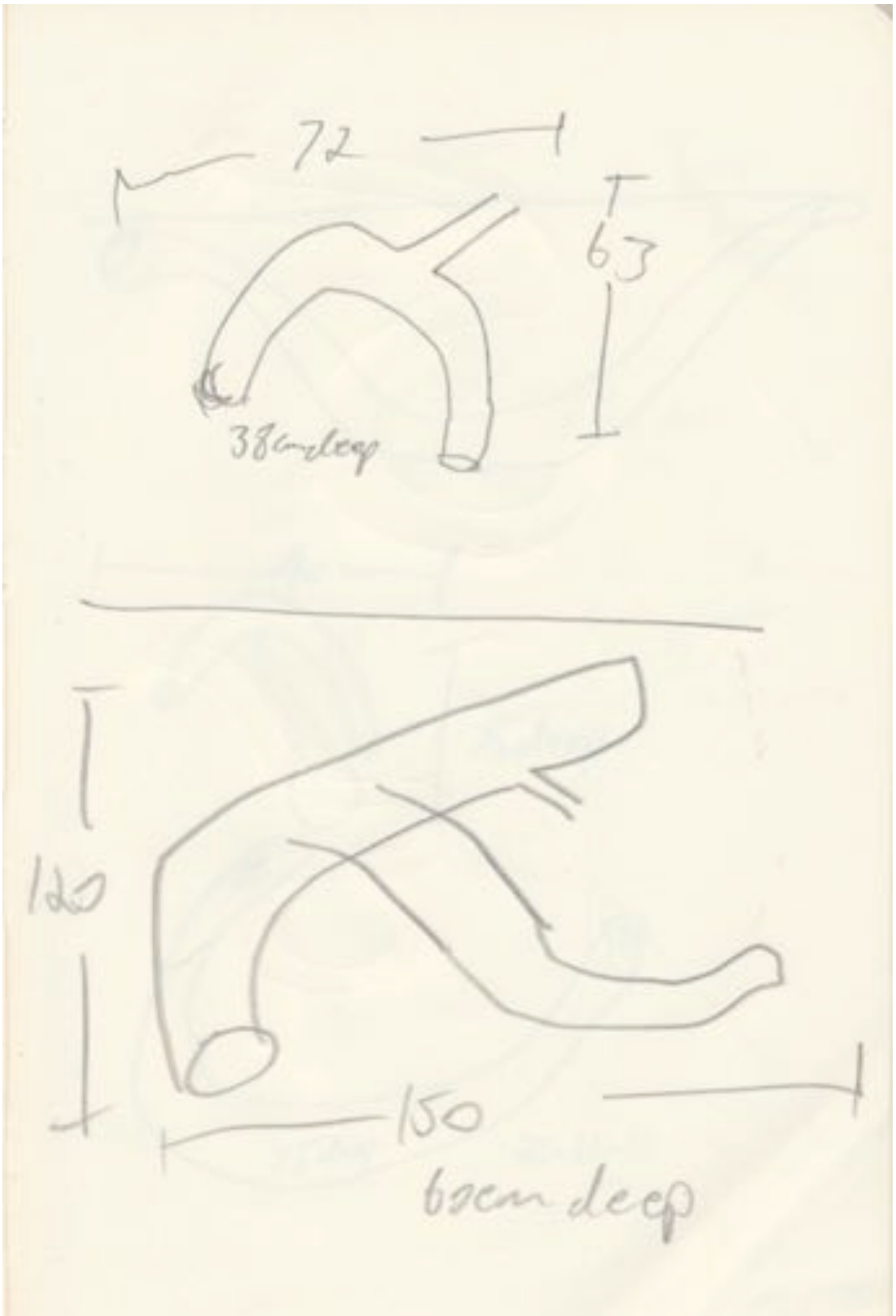


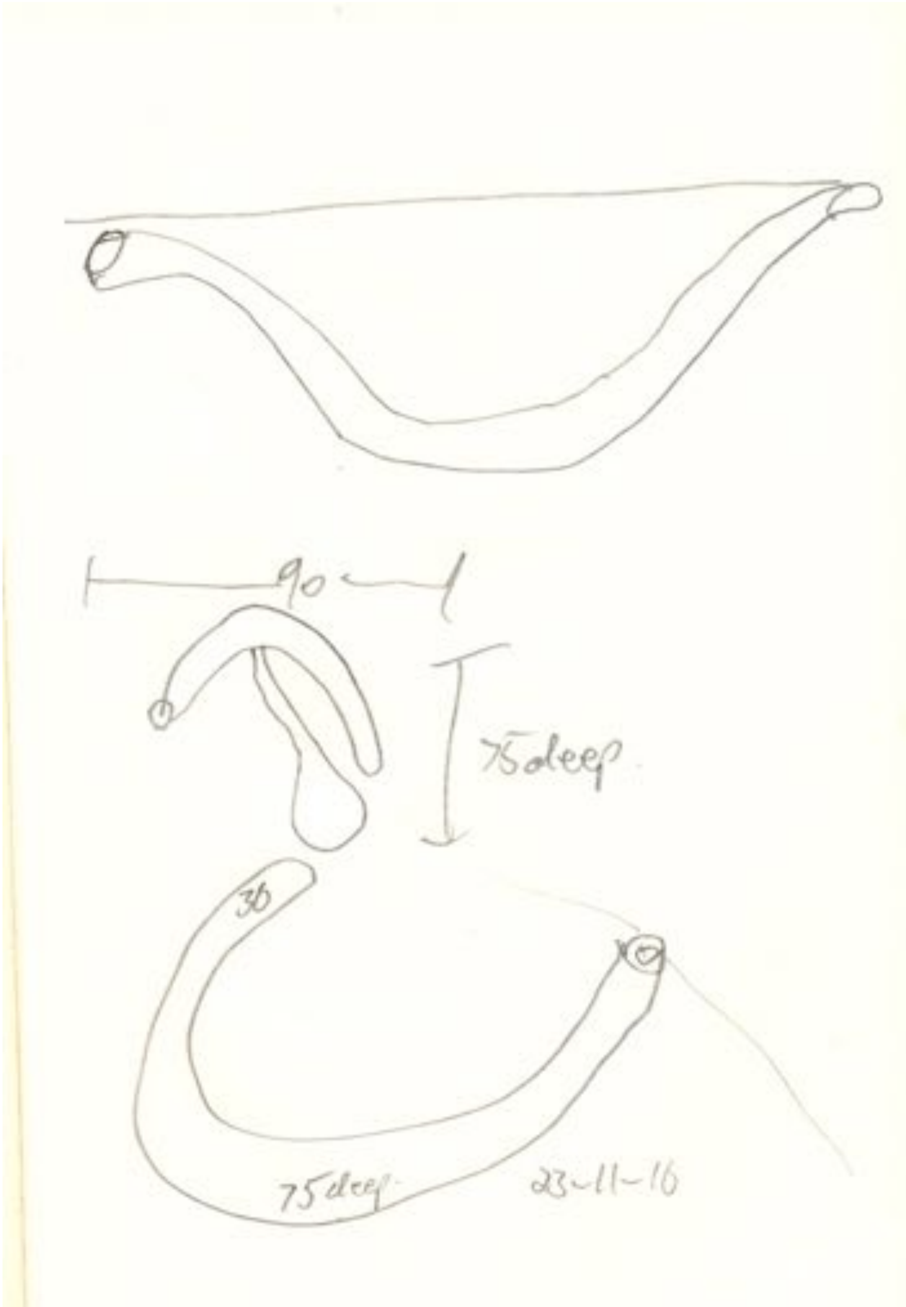

80
190
#136
60


74
84
25
33
$129.
23 November 2016.
legs
88
65

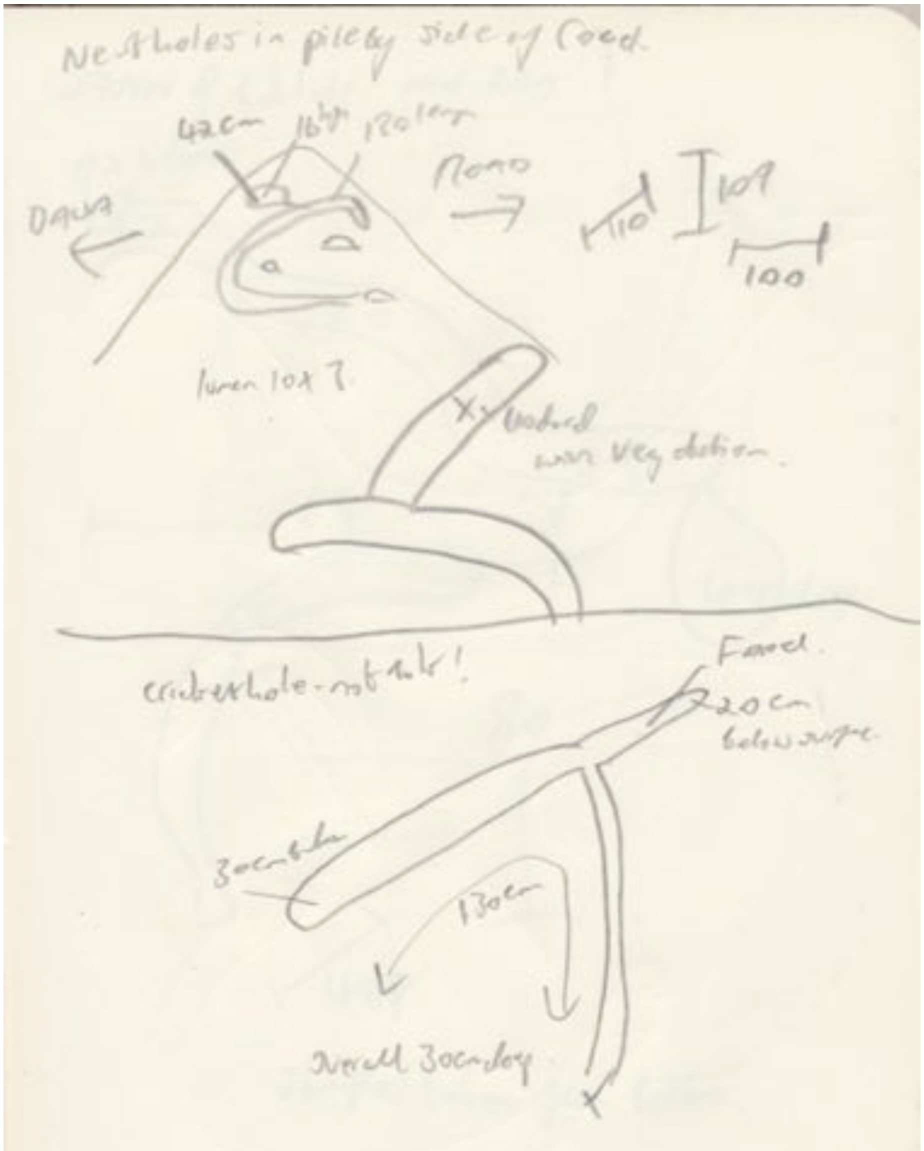

58
33
67

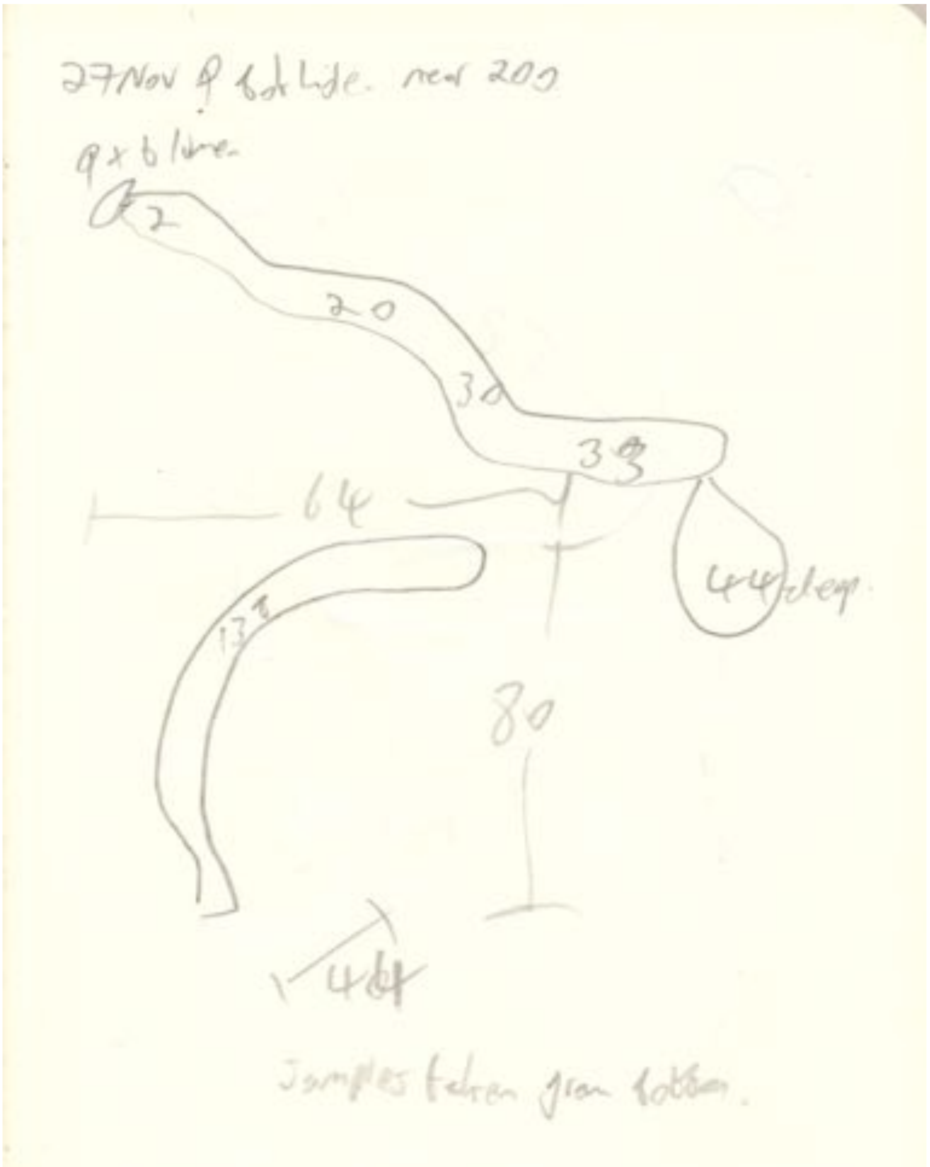

90
150
max. depth 120
No eggs.
90
120


72
63
38cm deep
120
150
60cm deep



90
75deep
30
75 deep
23-11-16


Nest holes in pile by side of road.
42cm
DAWA
ROAD
110
109
100
lumen 10 x 7
100 cm
Road.
20cm
below surface
30cm
Overall 30cm deep


20
30
64
80
44
deep