Seeing the heat with inexpensive thermography: natural history observations on the northern viper (*Vipera berus*) and grass snake (*Natrix helvetica*)

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ABSTRACT - The advent of thermal imaging (TI) cameras that attach to smartphones has dramatically reduced the cost of thermography. TI cameras are now within easy reach of naturalists and this has given an opportunity to field test one model, the FLIR ONE, on grass snakes and northern vipers. The potential of the camera to provide useful insights into snake thermal ecology is demonstrated in six short case studies; a further three case studies highlight some practical constraints. The main constraint was that although the camera contributed very precise temperature measurements, to 0.1˚C, individual measurements did not always correspond to independently measured values. Nevertheless, the temperature differences between subjects were well maintained, even following automatic recalibration of the camera. Consequently, the temperature differences between subjects in the same sequence of thermographs are reliable and the case studies demonstrate that these can be very informative. For example, they show the patchy heat distribution across the artificial refuges used in reptile monitoring; the thermal imprint of a grass snake resting below a refuge; and the warming of a female viper basking on an ant hill, where the rate of warming seemed to differ between the front and back end of the snake. The camera was fun to use and there is still great potential for thermography to reveal the thermal secrets of reptiles in natural environments and as an adjunct to captive husbandry.

INTRODUCTION

Measurement of the infrared (IR) radiation emitted from reptiles is a convenient and non-invasive way to estimate body surface temperatures. Such measurements could be made using either IR thermometer guns or thermal imaging (TI) cameras. Most previous field studies have used IR thermometers as they are relatively inexpensive, usually costing less than fifty pounds. In contrast, until recently TI cameras have cost thousands of pounds. With the advent of TI cameras that attach to smartphones, the cost barriers have been lowered to a few hundred pounds so their use is now within easy reach of many naturalists.

TI cameras have a two dimensional array of detector elements that create a recognisable thermal image (thermograph). In contrast, an IR gun is equipped with a single detector element that senses IR radiation emitted from a very small spot on the surface being tested, equivalent to one pixel in a thermograph. Consequently, thermographs show a great deal more information about the temperature of both the animal and its immediate environment. IR guns must be used relatively close to the subject of study as they are constrained by distance to spot size ratios that typically range from 8:1 to 12:1. This ratio is an optical characteristic of the system and at 8:1 the thermometer will sample the temperature from a 1 cm diameter target when it is 8 cm away. If IR gun is moved further away then a greater area is sampled, potentially including temperatures from more than just the subject of study. TI cameras generally have somewhat greater distance to spot size ratios and so can be used at greater distances from the subject. However, manufacturers do warn that the accuracy of the temperature readings is reduced with increasing distance from the subject as infrared radiation may be attenuated by atmospheric absorption.

Now that TI cameras are available at relatively low cost, an opportunity was taken to test one model, the FLIR ONE, to see what natural history observations could be collected on the northern viper (*Vipera berus*) and grass snake (*Natrix helvetica*). Nine case studies were developed to show the use of the camera and the interpretation of thermographs in different field situations. The first four case studies deal with artificial refuges and snakes beneath them, two are devoted to snakes in the open, and finally there are three focusing on some of the constraints when using the FLIR ONE.

METHODS

General methods are presented in this section while methods specific to a particular case study are dealt under the relevant heading.

TI camera

The TI camera used in this study was the ‘FLIR ONE TM’version 2 (FLIR Systems, Inc., USA). This was attached to the micro USB port of a Samsung Galaxy Note 5 android smartphone. For ease of use in the field the smartphone was clamped to a tripod mount and camera pistol grip (Fig. 1).

The FLIR ONE comprises a thermal imaging camera (FLIR Lepton 3) and a light camera (VGA 640 x 480). On taking a picture both cameras are activated and the resulting images are combined by MSX TM technology. The advantage of this approach is that the combined image is much more recognisable than a thermal image alone. To create this contrast, it is the negative of the light image that is combined with the thermal image; this creates an interesting effect as the bold patterns of snakes will appear

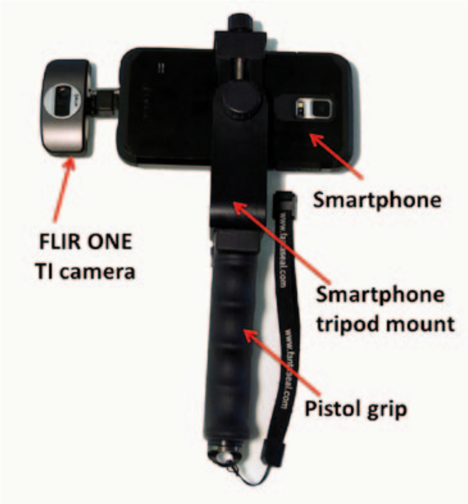

Figure 1. FLIR ONE thermal imaging camera attached to a smartphone that is held in a tripod mount bolted to a camera pistol grip

in negative (i.e. dark where it is normally light and vice versa). An app in the smartphone is required to operate the FLIR ONE. Two are available, one from FLIR can be downloaded free of charge or the other, the Thermal Camera plus which is FLIR approved, can be purchased. Both were used during this study. For manipulating the thermographs on the smartphone, or more easily on a computer, FLIR Tools can be downloaded for free. In FLIR Tools it is possible to toggle between the light and thermal images or adjust the balance between the two. Also when using FLIR Tools it is possible to display 'spot temperatures' (in effect similar to IR gun readings) by adding cross hair sights. At the intersection of the cross hairs there is a circle that shows the area from which a temperature estimate is being taken and gives a rough indication of the distance to spot size ratio; believed to be close to 40:1. In the current tests, the smallest targets reported had diameters typically of 1.5 cm to 3 cm and were photographed at a distance of 50 to 70 cm to avoid distance to spot size ratio issues. Spot temperatures were selected carefully in FLIR Tools by using the cursor keys to move the cross hairs over the chosen subject area to the location returning the highest temperature. Besides spot temperatures, in FLIR Tools it is possible to delimit areas by drawing ellipses or boxes on the thermograph for which average (mean), maximum, and minimum temperatures are displayed.

The Lepton 3 camera has a 160 x 120 detector array. Its scene temperature range is stated as -20°C to 120°C and operating temperature range 0°C to 35°C. It provides thermographs that resolve temperature differences as small as 0.1°C. The manufacturer suggests an accuracy of temperature measurement of ±2°C or 2%. The accuracy of the temperature measurement is dependent on the unit's calibration and from time to time the FLIR ONE will recalibrate automatically. The camera will appear to freeze for a moment while it does this as the Lepton's mechanical shutter is closed to create a dark frame to calibrate against. IR radiation is invisible to the human eye but not to the camera's sensors, which record variations in IR intensity and interprets these as different temperatures. The thermograph is formed by allocating different colours to different temperatures. Both in the apps and in FLIR tools a variety of colour palettes can be selected to give colour ranges that most suite the purpose of the study. It is also possible to select a 'saturation' palette in which only those parts of the image either above or below a temperature limit are coloured. Unless otherwise stated, images are displayed in 'Rainbow HC' palette.

Emissivity adjustment

The emissivity value of a subject expresses the proportion of radiation emitted, other IR might be transmitted or reflected; a perfect emitter (black body) has an emissivity of 1. The more accurately the emissivity of a subject is known the more accurately its temperature can be estimated. If emissivity is set too high for the subject then the observed temperature in the thermograph will be too low and vice versa. The FLIR ONE is set at a value of 0.95, an appropriate value for reptiles (Tracy, 1982; Tattershall et al., 2004). However, if subjects do not have an emissivity of 0.95 then this default is adjustable during processing in FLIR Tools.

IR thermometer gun

Comparisons were made between thermograph temperatures and those recorded by an IR gun (Foxnovo DT8380); the same unit as used by Hodges & Seabrook (2016a). In brief, this IR gun had a measurement range of -50˚C to +380˚C, a distance to spot size ratio of 8:1, and a resolution of 0.1˚C. Emissivity is fixed at 0.95. A clear plastic tube, 1.8 cm long and 1.8 cm wide, mounted on the front of IR gun acted as spacer from the subject. All measurements of snakes were made at the mid-body. A calibration curve for the IR gun had been prepared using a viper cadaver and laboratory calibration thermometer (Hodges & Seabrook, 2016a).

Observations under refuges

Many of the temperature measurements were made of vipers or grass snakes under refuges of galvanised corrugated-iron sheets (0.5 mm thick and 0.5 g/cm^2) camouflaged by spraying their upper surface with brown paint (Espresso, satin finish, Rust-oleum), referred to as tins, or roofing felt (Garage felt, green slate finish, Homebase, #242805, 2 mm thick and 0.3g/cm^2). They were both cut to the same dimensions (50 cm by 65 cm) and pairs, one of each type, were placed together in sunny locations. The operational temperatures to which the snakes were exposed under the

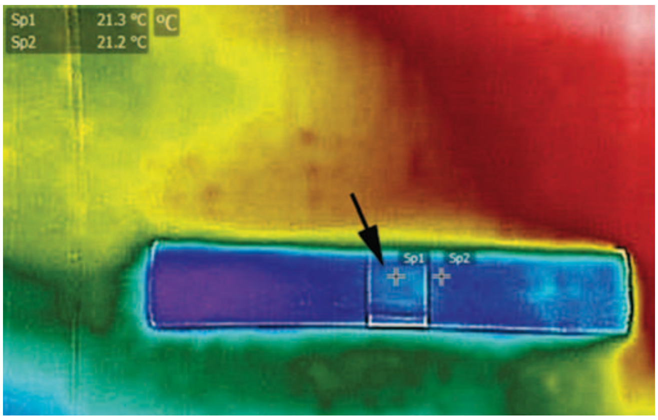

Figure 2. Testing the emissivity of the physical model by the application of a strip of black insulating tape (arrow) of 0.96 emissivity. The thermograph was taken at the default emissivity of 0.95. The tape (Sp1 =21.3˚C) was fractionally hotter than the adjacent areas of the model (Sp2 = 21.2˚C) indicating an emissivity of 0.95 for the model surface.

refuge tins were estimated using physical models (Hodges & Seabrook, 2016a). These consisted of copper pipe (ID 20 mm, wall 1mm thick, length 150 mm) sprayed with grey paint (Surface primer, matt, Rust-oleum). Such models have similar thermal properties to small snakes (Peterson et al., 1993). By indicating the temperatures available to snakes below the refuges they serve as null models for quantifying the extent of thermoregulation. To determine the emissivity of the tin and roofing felt refuges, and the physical models, a check was made by testing them against black tape, Scotch Brand 33 black vinyl electrical tape with known emissivity of 0.96 (FLIR, 2015). The estimated emissivity values for tins, roofing felt and physical models (Fig. 2) were approximately 0.95. Consequently, no corrections for emissivity were required.

RESULTS

Observations of refuges and snakes beneath them

Case study 1 - The heat distribution on refuge surfaces (30 May 2017, 09:34 h)

Thermographs were taken of 15 pairs of adjacent tin and felt refuges in full sun with the camera held 70 cm away from, and normal to, the subject. In all cases the refuge surfaces showed a patchwork of temperatures, those in Figure 3 are typical and look like a rather nice piece of modern art. The box function in FLIR Tools was used to check temperature ranges across the refuges which varied by 8.0˚C for the tin and by 5.2˚C for the felt.

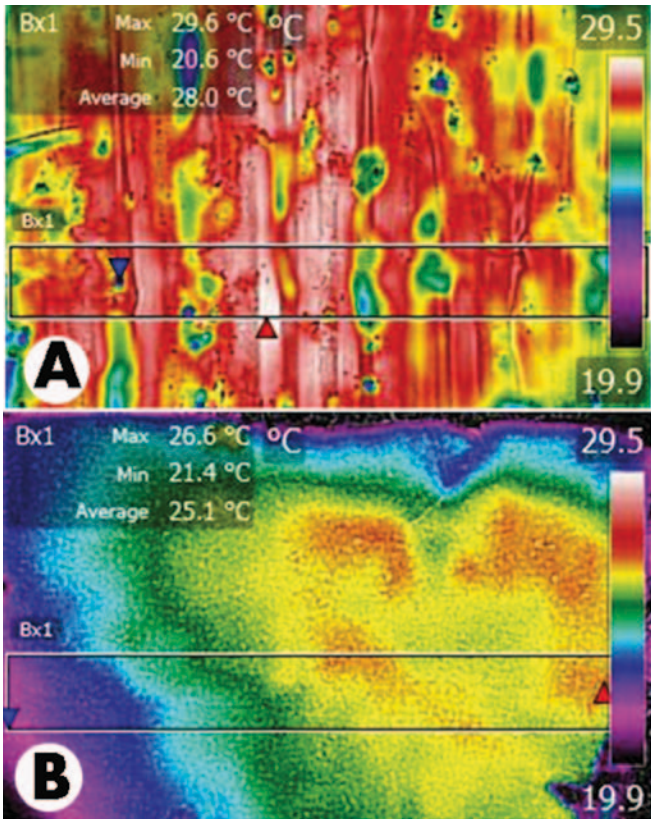

Figure 3. A. Thermograph of a tin refuge, **B.** Thermograph of an adjacent felt refuge. The boxes on each refuge, drawn in FLIR Tools, return the average (mean) temperature as well as maximum and minimum (indicated by a red and blue triangle respectively)

The pattern of temperatures also varied between tin and felt with tins tending to be more diverse (broken up). This is understandable as being corrugated both the angle of the tin to the sun and contact with the ground below is more variable than for a flat piece of roofing felt. The variations in refuge temperature are clearly an advantage to any reptile attempting to thermoregulate as there are different temperatures to choose from. This is demonstrated in the next case study.

Case study 2: Female viper and physical model under a refuge (20th August 2017, 10:48 h)

A gravid female viper was observed sheltering under a tin, beneath which there was also a physical model. During a period of two hours the refuge was in full sunlight, after which, at a distance of about 60 cm and normal to the subject, a thermal image was taken of the tin. The tin was then lifted and a further image taken of the physical model and viper.

The refuge showed a typically varied pattern of temperatures and across a central section ranged from 45.3˚C to 59.3˚C with a mean of 55.1˚C (Fig. 4A). Under the refuge the physical model and viper showed quite different temperatures from both the tin and from

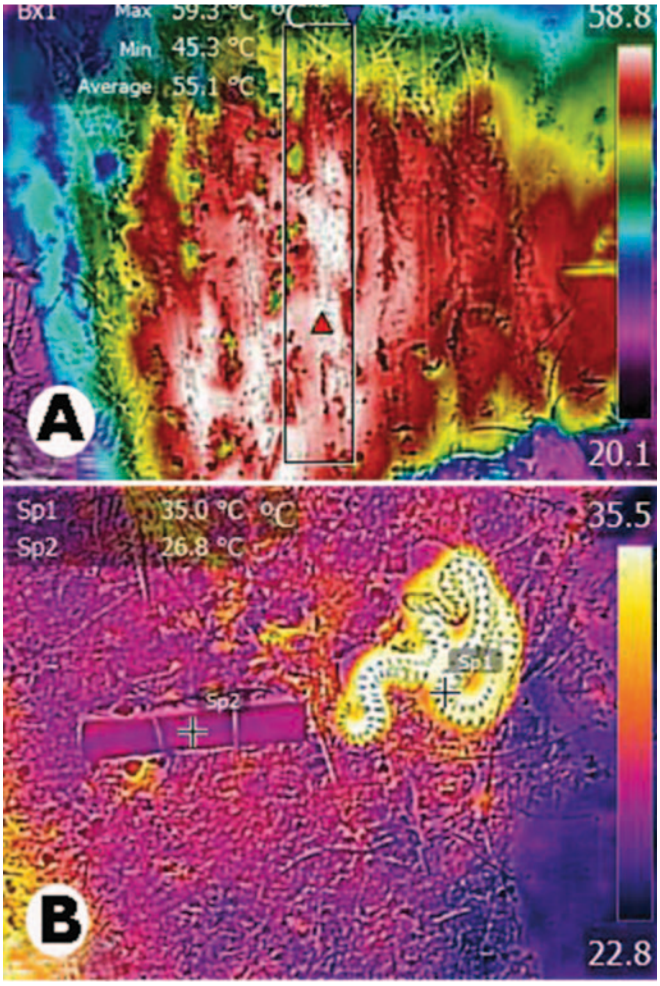

Figure 4. A. Thermograph of tin refuge with a box showing maximum (red triangle), minimum (blue triangle) and the average (mean) temperatures, **B.** Beneath the same refuge an adult female viper and physical model. This image is in 'Iron palette' to emphasis the fact that it has a different temperature span (22.8˚–35.5˚C) from 4A. Note the viper markings are displayed a negative image (see 'Methods' for explanation).

each other (Fig. 4B). The model at 26.8˚C was similar to the temperature of the ground below the refuge while at the mid-body the viper temperature was very much higher at 35.0˚C. However, the viper was not actually as hot as suggested in the thermograph as measurement at the mid-body using the calibrated IR thermometer gun indicated a temperature of 29.4˚C. Differences between the thermograph temperatures and those returned by the IR gun are dealt with in Case study 8.

The physical model is in a fixed position and its temperature is determined by its position below the refuge; different locations would probably have returned different temperatures. In contrast, the viper is free to move around to locate the most thermally beneficial position and alter its body posture to either increase or slow down the rate at which heat is gained or lost. Consequently, the viper was much warmer than the model. At 29.4˚C the viper is still some way below its upper thermal set point of around 32˚C (Hodges & Seabrook, 2016a) and so is not in danger of overheating despite the high temperature of the refuge above it. Perhaps the relatively low temperature of the ground prevented it reaching the upper thermal set point.

Case study 3 - Thermal imprint of a grass snake (18th May 2017, 12:52 h)

During an overcast period, a thermal image was taken at 70 cm and normal to a tin refuge. The surface of the tin had a distinct small warm patch with mean temperature of 19.9˚C (Fig. 5A). The tin was lifted and two further images were taken at 50 cm. The first was taken ten seconds after lifting the tin and immediately below the tin's warm patch was a grass snake; it had a mean body temperature of 24.2˚C (Fig. 5B). The second was taken five seconds after the snake had departed and was a warm patch on the dry bracken where the snake had been resting; it had a mean temperature 20.8˚C (Fig. 5C).

It is interesting to note that the precise position of the warm patch on the tin corresponded with the position of the grass snake below and likewise the dried bracken below the snake was also warmer than that surrounding it. It would appear that the warm patches on the tin and vegetation were the thermal imprints of the grass snake. The tin would have warmed up in earlier sunshine but when the sky became overcast would have started to cool down. The rate of cooling of the tin would have been faster than the grass snake below because corrugated iron has a lower specific heat (about 0.45 cal/g-˚C) than a grass snake which is mostly water (1 cal/g-˚C). Consequently, the thermal inertia of the grass snake appears to have maintained a warm patch on the tin. It is perhaps unexpected to find a reptile warming the refuge above it. In overcast conditions warm patches on tins might be reasonable indicators of reptiles below although this is unlikely to be a practical monitoring procedure.

Grass snakes have an upper thermal set point of about 31˚C (Gaywood, 1990), consequently the specimen in this example (mean body temperature 24.2˚C) would probably seek a warmer position if one was available (see Case study 4). Until it was disturbed, the grass snake had maintained its position despite losing heat. The thermograph shows the snake to be at the warmest point in a thermal gradient. It is not known what behavioural cue, e.g. reaching a specific low body temperature or rate of temperature decline, would eventually have led it to move away from the tin to seek warmth elsewhere.

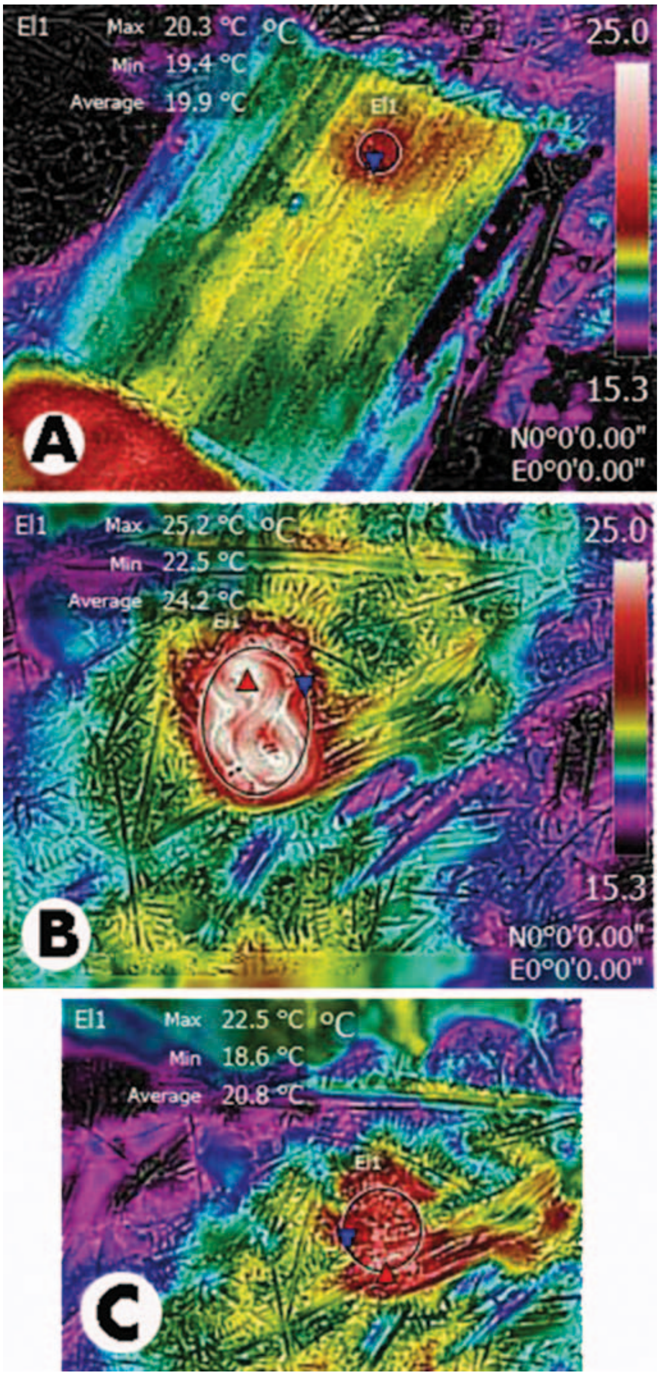

Figure 5. A. Tin refuge with a small warm patch (mean 19.9˚C), **B.** A grass snake coiled below the warm patch of the tin (mean 23.6˚C), **C.** Five seconds after the grass snake had departed showing a warm patch on dried bracken (mean 20.8˚C). Ellipses have been drawn on images to return average (mean), maximum (red triangle) and minimum (blue triangle) temperatures.

The next case study considers an observation of a viper and a grass snake below the same tin refuge.

Case study 4: Male viper and a grass snake under the same refuge (31st July 2017, 11:08 h)

A refuge tin in dappled sunlight (Fig. 6A) was found to be sheltering both a grass snake and a viper (Fig. 6B). Thermographs of both tin and snakes were taken at 60 cm and normal to the subject. The snakes were directly below the warmest part of the refuge which the thermograph showed was at 18.6˚C (Fig. 6A). Interestingly, the hottest spot temperature for each of the two snakes was also 18.6˚C (Fig. 6B). Measurement of the viper temperature at the mid-body using the IR thermometer gun indicated 18.4˚C. The very close correspondence between the mid-body temperature as measured by thermography and IR gun is typical when body temperatures are in the region of 18˚C (see Case study 8).

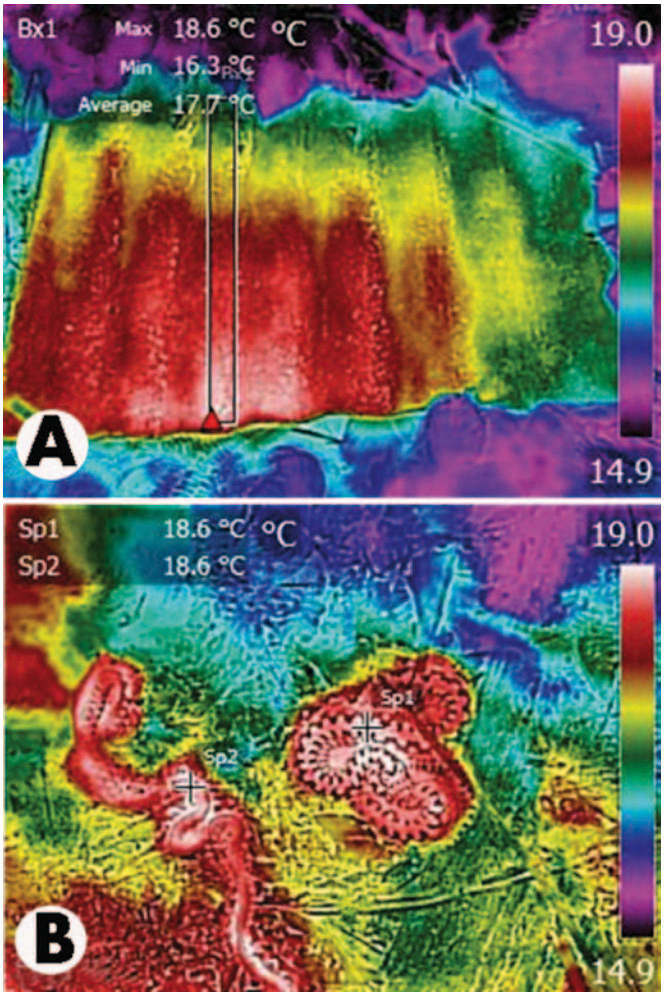

Figure 6. A. Thermograph of tin refuge with a box showing average (mean), maximum (red triangle) and minimum (blue triangle) temperatures, **B.** Grass snake and adult male viper beneath the same refuge both with maximum spot temperatures of 18.6˚C

The grass snake is shown as uncoiled (Fig. 6B) but prior to lifting the refuge it had been coiled up close to the viper. Clearly, under the prevailing conditions both snakes had attained the same, or at least very similar, body temperatures. The variations in temperature shown across the surface of the refuge suggests that there was a choice of different thermal conditions but the snakes had chosen the highest available to them. However, the situation was clearly thermally limiting since the snakes would normally allow their bodies to reach their upper thermal set point of around 32˚C for the viper (Hodges & Seabrook, 2016a) and 31˚C for the grass snake (Gaywood, 1990). Although both snakes attained the same temperature the rate at which this was achieved may not have been the same due to differences in their abilities to thermoregulate, the northern viper having a more sophisticated behavioural repertoire (Spellerberg, 1976; Gaywood, 1990; Gaywood & Spellerberg, 1995).

The case studies so far have focused on northern vipers and grass snakes under refuges. The next two deal with observations in the open.

Observations in the open

It is difficult to take thermal images of grass snakes in the open as they tend to move off rather quickly whereas vipers are more tolerant, especially if you move slowly, stay down wind and avoid casting a shadow over them. In long-term monitoring on chalk grassland there are quite big annual variations in the proportion of northern vipers encounters made in the open, which from 2008 to 2015, ranged from 20% to 60% (Hodges & Seabrook, 2016b).

Case study 5: Female viper warming on an ant hill (27 May, 2017, 07:48 – 08:06 h)

On a west facing slope, a gravid female viper was observed using the top of an ant hill to warm up in the early morning (Fig. 7A). The ant hill on top was sparsely covered with vegetation so that the substrate was mostly fine soil. This situation offered an opportunity to take a series of shots of the viper as she warmed up in the morning. To do this the TI camera was mounted on a tripod at 75 cm from the surface of the ant hill and adjusted to be normal to the location where the snake habitually sunned herself. The camera and photographer were in place early in the morning before the sun fell on the ant hill, located so that they would not cast a shadow.

The female viper emerged from the undergrowth at 07:48 h, with a body temperature that appeared to be at about the same temperature as the vegetation at the base of the ant hill, front third and back third of the snake were 19.8˚ and 18.8˚C respectively (Fig. 8). The top of the ant hill already had patches that were much warmer, a box estimate across the surface gave a mean temperature of 24.8˚C (max. 30.4˚, min 19.6˚). By 78 sec after emergence the snake had draped its body across the top of the ant hill (similar to Fig. 7A). The body was flattened and the tail more obscured by vegetation than the rest of the body. Over the period of 18 minutes both viper and ant hill surface warmed up but the ant hill was always a little hotter than the viper (Fig. 7B). The front third of the viper remained warmer than the back third (Fig. 8), so that over the whole observation period the mean body temperature values were 24.7˚ C and 23.2˚C respectively. The rate of warming of the front and back thirds were 0.54˚C and 0.48˚C/min respectively while in the same period the ant hill surface warmed at only 0.29˚C/min but was still warmer than the snake at the end of the observation period due to its head start. The reason for the difference in warming rate between the front and back thirds of the snake could be that the tail was in more dappled sunlight than the rest of the body and/or subtle variations in orientation to the sun between back and front. In any case, it would seem that the blood circulation system did not even-out the difference. It has been shown, at least in the case of the garter snake (*Thamnophis sirtalis*), that when cold the snake reduces blood flow to the tail and significantly increases it to the heads and vice versa when hot (Amiel et al., 2011). As a sophisticated thermoregulator, it seems likely that northern viper may do the same.

So far all the observations on vipers have been on the usual colour morphs. However, colour can affect the rate

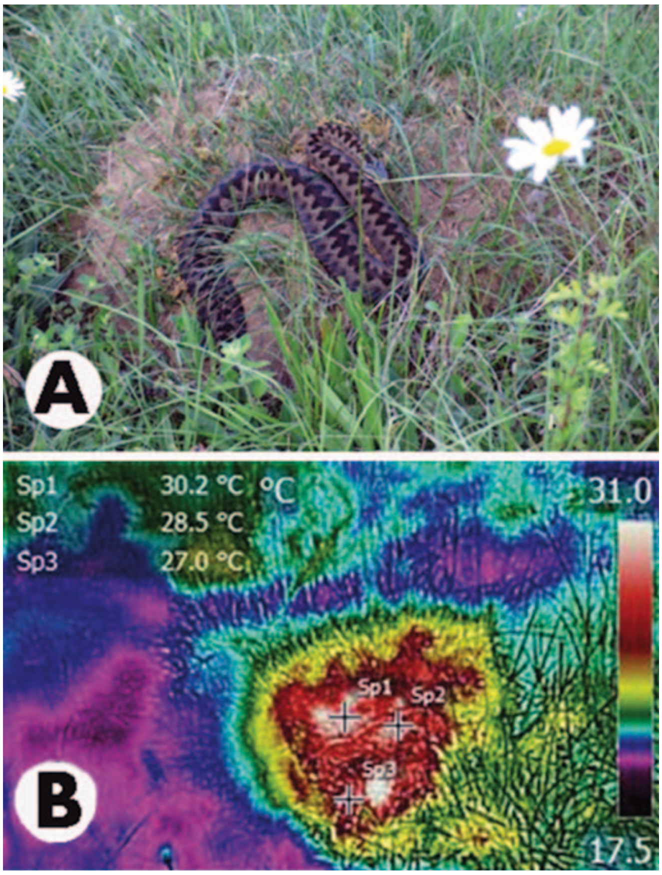

Figure 7. A. Light photograph of a gravid female viper basking on top of an ant hill, **B.** Thermograph of the same viper 25 min 45 sec after the start of thermography basking on the same ant hill (spot temperatures Sp1 – top of ant hill, Sp2 front third of viper, Sp3 back third of viper)

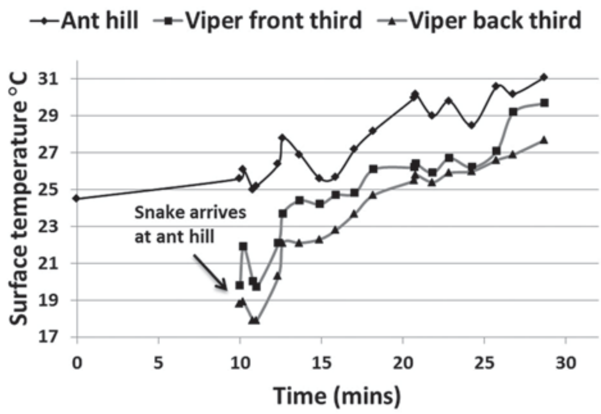

Figure 8. Temperatures of an ant hill surface and of the front and back thirds a female viper basking on top of the ant hill (as in Fig. 7)

of heat loss or heat uptake from snakes. The next case study offers an example of this from a black (melanistic) viper.

Case study 6 – Temperature difference between a melanistic and normal morph viper (18 April, 11:28 h)

In April, a black male viper was observed 'mate-guarding' a normal morph female in the open (Fig. 9); male vipers often remain with females for several days post copulation. The pair was observed basking together undisturbed for 20 minutes after which a series of thermal images was taken; the closest (Fig. 10) was from 70 cm and at an angle of 45˚. The black male viper appears to be 1.6˚C warmer than the female (Fig. 10A). This difference can be highlighted using the saturation palette of the TI camera (Fig. 10B).

Figure 9. Light camera image of a melanistic male viper mate-guarding a normal coloured female

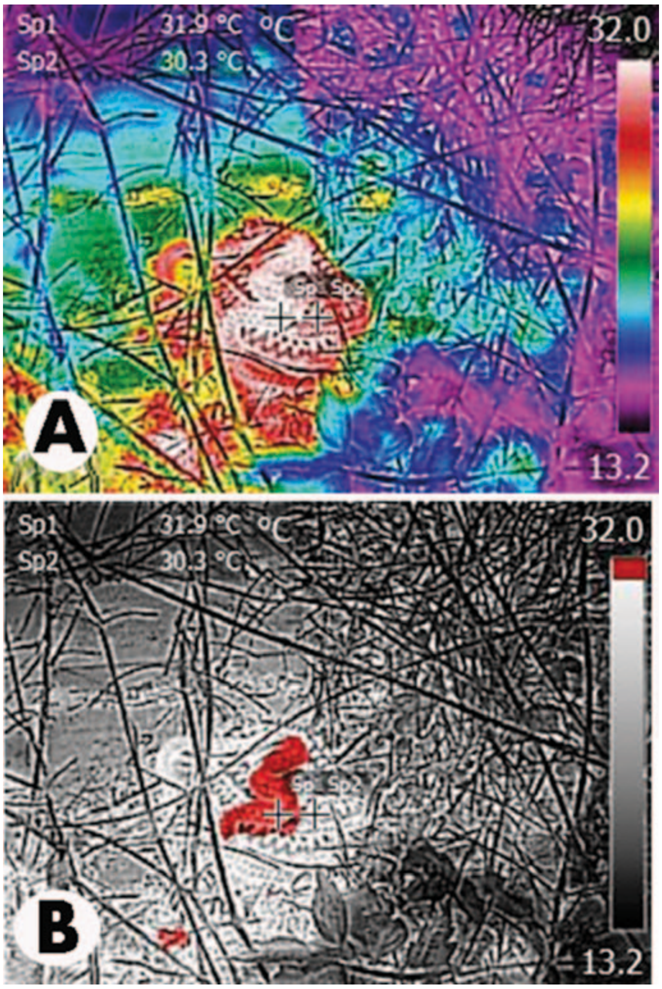

Figure 10. A. Thermograph of a melanistic male viper lying on a normal coloured female (shown in Fig. 9), the male is warmer (31.9˚C) than the female (30.3˚C), **B.** The same thermograph as 10A. but demonstrating the use of the saturation palette which colours only the hottest areas in red (selected to be above 31.1˚C)

Differences in heating rates between melanistic and normal colour morphs are expected as the black colour would make the animal more efficient at absorbing the wavelengths of light visible to humans. It has been suggested that this results in significant fitness benefits to black vipers which grow faster (Andren & Nilson, 1981; Trullas et al., 2007). However, there is also a disadvantage as black male vipers suffer a greater predation rate (Andren & Nilson, 1981). The faster warming of black vipers has been demonstrated under experimental conditions but was not detected in studies under natural conditions (Forsman, 1995). Unfortunately, the thermograph in our study (Fig. 10) does not contribute to our understanding of the heating rate in the field for two reasons. First, it could be argued that the female was not warming more slowly due her normal colour but due to a larger body volume that would result in greater thermal inertia. Second, being on top of the female, the male was probably being insulated from the cold ground below.

The next three case studies demonstrate some of the constraints when using a TI camera.

Observations on the constraints of using the TI camera

Case study 7 – TI camera re-calibration

An important feature of the TI camera is that from time to time it will recalibrate itself. This is explained in more detail in the Methods section. Recalibration occurred during a sequence of shots of a viper beneath a tin refuge and next to a physical model. The camera was about 50 cm away and normal to the subject. This gave an opportunity to examine the temperatures before and after recalibration. During the first 15 sec after lifting the refuge, the temperature of the snake at its head and mid-body and the physical model declined by about 1˚C at a mean rate of 0.076˚/sec. This was to be expected as heat escaped from beneath the refuge (Fig. 11). The camera then started recalibration which was soon completed so that the next shot was taken at 19 sec. The temperatures of the snake head and mid-body and the physical model were all increased by 2˚C in the first shot following recalibration, i.e. more or less retained the differences from each other but gave higher absolute values. Thereafter, the temperatures continued to decline but at a slightly lower rate than before, 0.04˚/sec. It seems that the period of most rapid heat loss from under the refuge was apparently passing and even after 43 sec the temperature was still above the lowest value before recalibration.

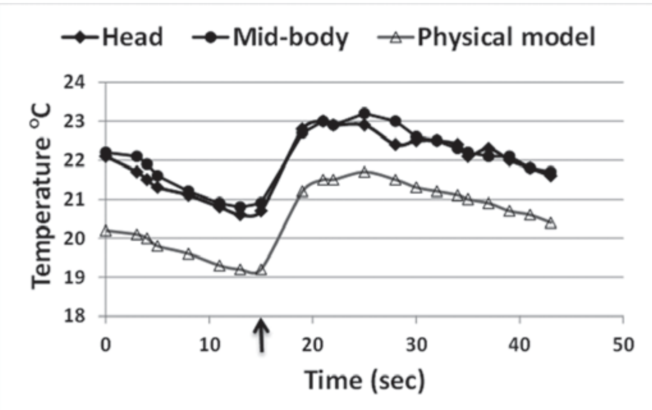

Figure 11. TI camera temperature measurements of the head and mid-body of an adult female viper and a physical model below a tin refuge taken over a period of 43 sec. At 16 sec the camera made an automatic recalibration (arrow). The apparent temperatures after recalibration were all increased by about the same amount

This experience with re-calibration shows that the absolute values returned by the thermograph cannot be relied upon but that the relative values correspond well. In other words, when looking for differences between subjects then the thermograph gives a consistent result but the actual temperature of the subject is uncertain.

Case study 8 – Accuracy of the temperature in a thermograph

Unlike the IR gun, the TI camera was not calibrated for viper body temperature measurement. During the course of 2017, many opportunities were taken to test viper body temperature at the mid-body using the TI camera with a paired IR temperature gun measurement made either before or after the thermograph. Nearly all measurements were taken of vipers found below refuges and the camera was operated using either of the two smartphone apps that are available for the purpose.

There was no systematic difference in the temperatures recorded using the two different mobile phone apps (Fig. 12). However, if the viper surface temperature at the mid-body was below 20˚C by IR gun then nearly all corresponding thermograph temperatures were lower than that. Conversely, if the mid-body temperature was above 20˚C by IR gun then the corresponding thermograph temperatures were higher (Fig. 12). Only 31% (14) of the temperatures observations fell within the accuracy range quoted by the manufacturers ±2˚C (Fig. 12). The wide variation between IR gun and TI camera suggests there would be little value in preparing a calibration for the TI camera based on this data.

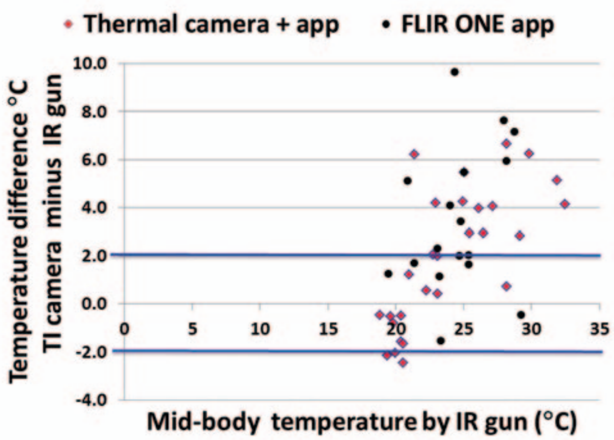

Figure 12. Differences between body surface temperatures (˚C) of vipers estimated by TI camera and by IR gun, plotted against the body temperature estimated by IR gun. The data were gathered using two different smartphone apps. Values within blue lines show variation expected by manufacturer's specification (±2˚C). N = 45

Case study 9 - Effect of reflections on body temperature in a thermograph

Reflected infra-red radiation could interfere with the temperatures observed in a thermograph. An example of this is a thermograph of a pane of glass. Glass is a good reflector of infra-red but transmits visible light and as a consequence we can see a scene through a glass window (Fig. 13A). But when viewed as a thermograph, which detects the reflected infra-red radiation, the window shows the temperature of the photographer not a scene through the window (Fig. 13B). Likewise there is the potential for snakes' scales to reflect sunshine so that thermographs taken in sunshine and those in shade may differ in the amount of reflected radiation. The degree to which reflection is a problem could be affected by the angle at which the thermograph is taken; at some angles reflection may be more problematic than at others.

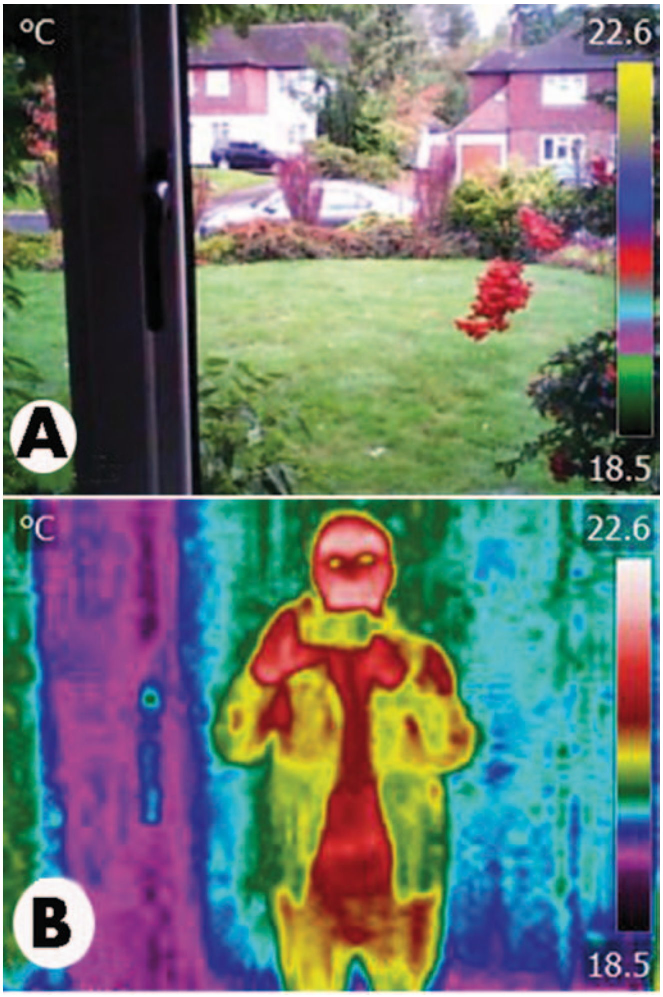

Figure 13. A. Light photograph taken through a window, **B.** The corresponding thermograph (not combined with light image) showing the reflected thermal image of the photographer who is wearing glasses so has cool eyes

Table 1. Temperature estimates at the mid-body a female viper from thermographs taken five seconds apart in sun and then in shade at four different angles, to examine whether there might be sunshine reflected from scales

Camera angle	In sun	In shade	Difference
90˚	28.3	28.7	+0.5
70˚	27.1	27.0	-0.1
45˚	27.2	26.4	-0.8
30˚	26.4	26.1	-0.3

An opportunity was taken to observe whether direct sun on a female viper would affect the temperature estimates of the snake. A thermograph was taken 60 cm from the subject and at a camera angle of 90˚. Immediately after, a shadow was cast across the snake and the thermograph retaken. This process was repeated with camera angles of about 70˚, 45˚ and 30˚. The temperature differences recorded in this process were small (Table 1) and suggest that at least for northern vipers sunshine on scales is of limited practical significance. This is perhaps not surprising as viper does not have particularly shiny scales.

CONCLUSION

The FLIR ONE is an inexpensive thermal imaging camera and consequently has a relatively low resolution. Despite this, it has been used to make interesting natural history observation on northern vipers and grass snakes. The case studies have given graphic illustrations of both known and previously unknown temperature effects and put temperature measurement into a broader context. Earlier studies on the thermal ecology of British snakes would have been much enriched had this technology been available in the 1990s (Gaywood, 1990; Vanner, 1990).

The TI camera clearly has one serious limitation; the temperatures shown in thermographs are not often very close to the actual (absolute) values obtained under field conditions with a calibrated IR temperature gun. It is possible that better agreement may have been possible in more controlled conditions, although the lack of agreement has also been the experience of medical researchers using sophisticated TI cameras (Heuvel et al., 2003; Andrade Fernandes et al., 2014; Bach et al., 2015). However, this need not be a serious issue if the interest is in relative temperatures, i.e. temperature differences between subjects. Temperature differences in thermographs have been the basis of previous controlled laboratory studies with reptiles, for example rattlesnake digestion (Tattersall et al., 2004). Such comparisons would still be valid even if the FLIR ONE recalibrates itself in the midst of a series of shots since temperature differences appear to be maintained. The user also has to be aware that the thermograph temperatures may well be impacted by reflections or draughts that could easily raise or lower temperatures and that adjustment is require when comparing subjects of different emissivity (FLIR, 2015). Likewise there are techniques to determine reflectance with suitable crumpled pieces of aluminium foil (American National Standard, 1998) so that reflectance defaults can also be adjusted in FLIR Tools. Another issue is that the temperature of mammals can be affected by stress; consequently taking thermal images of them should be done in a way that minimises disturbance of the subject (Cilulko et al., 2013). It would be interesting to know if the same applies to ectotherms such as reptiles.

The individual animals included in this study were adult or large sub-adults so that they were still of a reasonable size in thermographs taken from 50 cm to 70 cm. Consequently, the distance to spot size ratio issue does not appear to have affected the results. Small immature specimens remain to be tested and this would require the TI camera be brought much closer to the subject to be within the distance spot size ratio. There is no reason to believe that the results in these conditions would be any less valid and for macro shots there is a control in the FLIR ONE app allowing manual adjustment for parallax that would otherwise result in misalignment of the light and thermal images.

An understanding of thermal ecology is essential to the interpretation of reptile monitoring data (Gaywood &

Spellerberg, 1995). Thermal imaging has been a very useful addition to a long-term monitoring programme for northern viper and has the potential to make significant contributions to our understanding of vipers, both at refuges and in the open. When applied to other reptiles, thermal imaging will undoubtedly provide new and interesting insights into behaviour and thermal ecology. When applied to captive husbandry it may also offer a means of assessing and adjusting living conditions. Finally, as thermal imaging makes headway in the consumer market, naturalists may soon have access to even more sophisticated cameras at affordable prices.

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