

Rethinking Captive Heating: Effect of Infrared Radiation on the Radiated Tortoise (*Astrochelys radiata*)

Nicholas J. Willis^{1*}, Andrew Quayle¹ & James E. Brereton¹

¹University Centre Sparsholt, Hampshire

*Corresponding author: Nick_willis@hotmail.co.uk

Keywords: *Astrochelys radiata*, IR-A, IR-B, Heating, Husbandry

Abstract

In the wild, reptiles are exposed to the entire infrared spectrum (IR-A, IR-B and IR-C wavelengths), yet many zoological collections rely on IR-C to provide heat to their animals. This study investigated whether the addition of IR-A and B wavelengths affected the behaviour and enclosure use of a group of captive radiated tortoises (*Astrochelys radiata*). Modified Spread of Participation Index (SPI) was used to assess the evenness of exhibit use. This is the first published study using SPI on a reptile species, despite its practicality at addressing abiotic gradients and depth-based zones that are commonplace within herptile enclosures. The study identified a 31% reduction in tortoise basking behaviour when exposed to IR-A and B emitting bulbs ($p < 0.001$, $r = 0.402$) which simultaneously resulted in a wider variety of behaviours being expressed, including changes in inactivity ($p < 0.001$, $r = -0.309$) and drinking ($p < 0.001$, $r = -0.139$) behaviours. In addition to behavioural changes, the provision of IR-A light resulted in more even enclosure zone use, potentially making it an interesting application for improving herptile captive husbandry. IR-A and B lighting may be an important consideration for improving captive herptile welfare and facilitating an animal's expression of natural behaviours. Despite some interesting results, this study did not yield enough information to fully support the provision of IR-A lighting to captive reptiles, thus, future, more in-depth studies with larger sample size, observation counts and subjects amongst different taxa will be required. Potentially, with further studies and repetitions, this could have large and positive implications for the industry; ones that would derive from a relatively simple, and inexpensive/cost-effective change/modification of a light bulb. It is the author's aim that this work will provide a useful foundation for future studies.

Introduction

Reptiles within captivity are typically provided with a variety of light and heat sources for thermoregulation and vitamin D₃ synthesis (Baines *et al.*, 2016). These lighting arrays should theoretically replicate natural heat sources as closely as possible so that wild type behaviours and correct homeostasis can occur (Beaupre & Zaidan, 2012; Michaels *et al.*, 2014).

Historically, keepers have concentrated on 1) ultraviolet B (UVB) provision and its effects on vitamin D₃ production and 2) reptile heating systems to provide ecologically informed ambient temperatures. However, terrestrial organisms in the wild are exposed to the full solar spectrum, this includes infrared radiation (IR), which cannot be seen, but like visible light, can be perceived as heat (Wunderlich, personal communication, 2020; Barolet *et al.*, 2016; Schieke *et al.*, 2003). Much like UV, IR is not limited to just one type, but three different wavelength categories which are infra-red A, B and C (Barolet *et al.*, 2016; Schroeder *et al.*, 2008). IR-C is the furthest from visible light, this is often called 'far infrared' or FIR (Vatansever & Hamblin, 2012). Several reptile heating systems (ceramic heat emitters, heat mats, radiant panels, and cables) emit IR-C radiation (Figure 2), this begs the question: how important are the other wavelengths, IR-A/IR-B?

Infrared-A, known as 'near-infrared' or NIR, has a short wavelength band that enables photons to penetrate deeper into the subcutaneous skin, promoting a 'deep warming' effect that is further distributed by the circulatory system (Divers & Stahl, 2019). This provides heat deep within the muscle tissues, warming the animal throughout just as it would in the wild from the sun (Muryn, personal communication, 2019), without significantly increasing skin temperature (Cho *et al.*, 2009). The penetrative depth of IR-A has been recorded to 5mm up to 100mm in human models, whereas IR-B has a penetration depth of approximately 1-3mm and IR-C is around 0.1mm (Currà *et al.*, 2019; Ruggiero *et al.*, 2016; Sowa *et al.*, 2013; Brown *et al.*, 2002).

Porter (1967) investigated the presence of black peritoneum and what its biological function is. It is believed that it protects the inner organs against harmful UV rays which counters the argument that is to aid in thermoregulation. However, one of the most interesting points in the study, was the measurements of transmission and absorption in each tissue layer for the full solar spectrum (290 nm - 2600 nm). Porter measured how much light was reflected and absorbed in the upper epidermal, dermis, the muscle, and how much radiation was transmitted into the inner body cavity for the side-

blotched lizard (*Uta stansburiana*). The results indicate that the IR absorption is along a wide range of wavelengths, with each one being responsible for heating different cell types at varying depths. These results can be easily identified thanks to the recent work of Sarina Wunderlich (personal communication, 2020), who was able to use Porter's analysis and plotted the results in relation to the solar spectrum, helping display which wavelengths are absorbed in which tissue layer (see Figure 1).

The energy from IR-C sources, such as the commonly used Ceramic Heat Emitter (CHE) is mostly absorbed by animal surface tissues (stratum corneum), where it may cause localised overheating

whilst leaving other regions of the body too cool (Highfield, 2015). IR-C releases its energy via water molecules, which can create a dry environment due to the reduction of ambient humidity, this may potentially result in dermatological/keratin issues (Courtney-Smith, 2018; Divers & Stahl, 2019).

Due to IR-A penetrating further into the dermis than IR-C, it may result in IR-A emitting bulbs potentially improving and hastening the thermoregulation process. Thermoregulation is not the only application of infrared. Since the 1960s, infrared has been implemented in both medical and veterinary fields (Barolet *et al.*, 2016; Min & Goo, 2013). and is shown to minimise scar

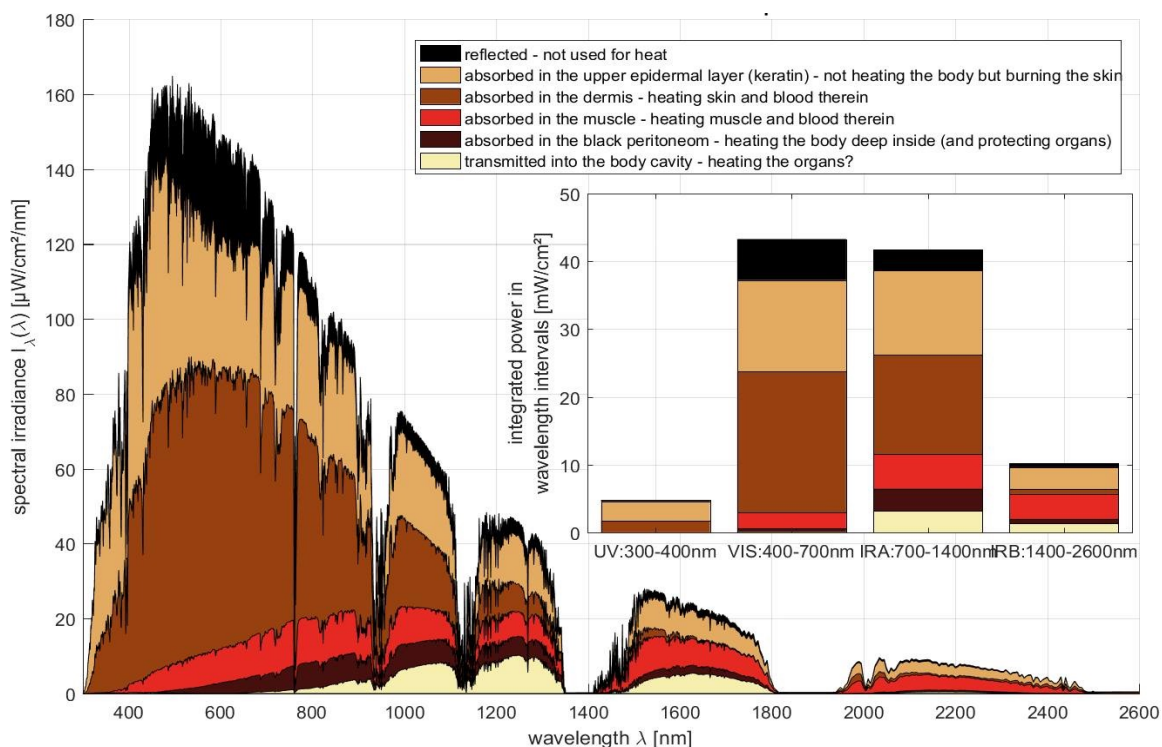


Figure 1. Penetration depth in relation to the solar spectrum for the side-blotched lizard (*Uta stansburiana*) and the result of integration along the wavelength-axis (ASTM reference spectrum AM1.5). Data was derived from Fig.5 from Porter(1967; Wunderlich, 2020). It is interesting to note that IRB (1400 nm - 2600 nm) did not heat the dermis yet managed to penetrate the muscle, and that IRA (700 nm – 1400 nm) and IRB had a larger heating effect on the muscles in comparison to VIS (400 nm – 700 nm).

tissue, downregulate inflammatory response and bruising, treat toxic insult and hypoxia, provide pain relief, combat autoimmune conditions via detoxification, and shorten recovery time (Baines pers. Comm, 2019; Cowles *et al.*, 2013; Chung *et al.*, 2011; Lopes *et al.*, 2007). IR-A exposure has also been theorised to precondition the skin to protect against deleterious ultraviolet radiation through photoprevention (Barolet *et al.*, 2016). Whilst the aforementioned examples may not be strictly related or necessary for husbandry practices, it is worth highlighting the medical significance of IR as to challenge the misperception that it is always deleterious to health (Barolet *et al.*, 2016). However, as with most things, moderation is important. According to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) statement, IR-A and IR-B poses a risk to corneas due to the penetration depth of the bands (Aly & Mohamed, 2011). Unfortunately, no reliable data currently appears to exist on the incidence of IR-related optical conditions in captive reptiles. Thomas *et al.*, (2019) investigated IR effects by looking at the behaviour of two (1.1) captive blue tree monitors (*Varanus macraei*) when provided with two different lighting arrays, a mercury vapour lamp and a Deep Heat Projector® (DHP, Monkfield Nutrition Limited). The difference between

these two bulbs was the amount of IR-A and B produced, as opposed to the absence or presence. The mercury vapour emits mostly IR-A with some IR-B and IR-C (Baines, personal communication, 2019), whilst the DHP emits a small amount of IR-A, with high levels of IR-B and IR-C (Figure 2). However, the Mercury vapour lamp also emits visible light and UV, resulting in the study having a 1.5-4 UVI difference between the two conditions. It has been demonstrated that UV can regulate behaviours such as; feeding, diurnal locomotion, courtship and influence agonistic, reproductive, and signaling behaviours (Reptile Lighting Guide, 2017; De Vosjoli, 2012; Lappin *et al.*, 2006) which may have affected the results. Despite this, Thomas *et al.* (2019) reported a significant increase ($\chi^2 = 12.200$, $P = 0.002$) in basking duration when the monitors were exposed to the DHP condition, which was associated with a statistical decrease ($\chi^2 = 18.617$, $P < 0.001$) in resting. Thomas *et al.* state that these results may be due to the DHP having lower levels of IR-A, and not allowing the monitor lizards to reach optimal internal temperatures, resulting in the animals basking for longer durations; a theory that this paper intends to address.

This study aimed to further the investigations initiated by Thomas *et al.* (2019) by designing a methodology that focuses on the removal/addition

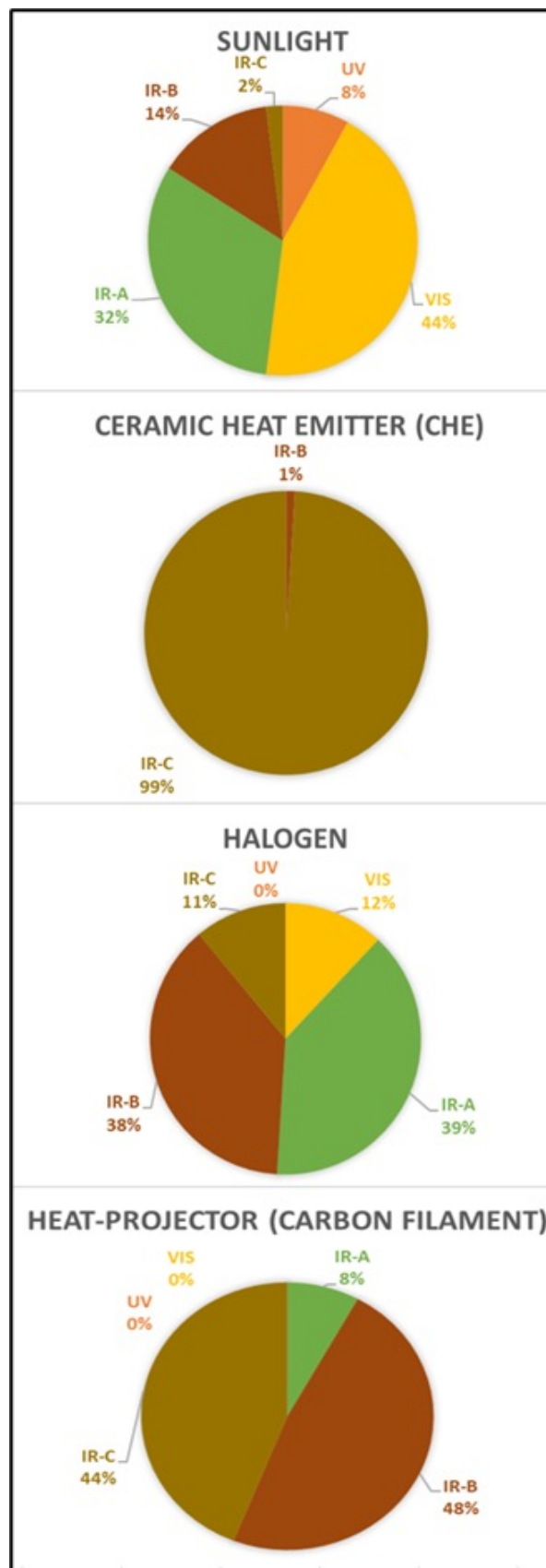


Figure 2. Charts display the percentage and type of wavelengths that are emitted from each bulb. A Spectrophotometer would have accurately measured the IR-spectrum, however, due to cost and logistics, it was out of scope for the purpose of this study (Authors own, 2020).

of IRA and B. Wavelength composition of sunlight, CHE, DHP and halogen bulbs were derived from theoretical blackbody radiation curves using kelvin (K) values from the manufacturer's specifications and the total solar irradiance (Figure 2). The charts identified that halogen lamps appear to replicate sunlight more accurately by emitting IR-A, B and C, whereas CHE produces primarily IR-C, making it appear to be the least effective at sunlight replication. The two bulbs fail to produce UV; however, UV bulbs can be provided additionally, which allow for the removal of an important extraneous variable. This is unfortunately not possible for visible light (VIS), as CHE is unable to emit this band, this was minimised by providing VIS in the form of LED lighting alongside the IR and UV lighting systems. However, the halogen condition will always produce more VIS, making it an extraneous variable; this might be an important factor if the subjects are heliothermic and use visible light as a cue for basking.

Methods

This study compares CHE with halogen bulbs (Richardson, 2001). The difference between CHE and halogen bulbs is the presence/absence of IR-A & B. This distinction allows a study to identify if IR-A and B wavelengths can influence tortoise behaviour and their choice in enclosure use. This study expands upon prior work by recording both

state and event behaviours, and the observation of enclosure usage amongst the individual subjects, this was also supported with the implementation of a modified Spread of Participation Index (SPI).

Study subjects and location

The study was conducted at Sparsholt College, Winchester, UK, on a 2.3 group of radiated tortoises (*Astrochelys radiata*). Data was collected between 27/09/19 – 02/02/20, during the hours of 1100-1600. The research was approved by the Ethics Committee at the University Centre Sparsholt, Winchester and abided by the Association for the Study of Animal Behaviour Ethical Guidelines (ASAB, 2017).

The *A. radiata* group (Table 1) was housed in an indoor enclosure (W93" x D60" x H34"), with a surface area of 3.6m² (Plate 1). The enclosure consisted of a hot and cool end, with a hide/shelter located at the cool end. A humid area containing sphagnum moss was also provided. Sand and soil were used as substrate with rocks situated around the enclosure.

Daily husbandry routines were kept the same to avoid any potential changes in subject behaviour. Main feeds were in the afternoon, this consisted of 300g of seasonal vegetation, such as cabbage, dandelions, plantain, hazel leaves and root vegetables. Portion sizes remained the same throughout the study.



Table 1. Subject information

Colour ID	Sex	Hatch Date	Weight (kg)	Remarks
Black	♂	2011	4.82	Captive bred (arrived at collection in 2014)
Blue	♂	Unknown	3.11	Wild caught (seizure from customs)
Pink	♀	Unknown	3.84	Wild caught (seizure from customs)
Red	♀	Unknown	3.29	Wild caught (seizure from customs)
Green	♀	Unknown	5.04	Wild caught (seizure from customs)

Data collection started an hour after the food was initially presented to avoid extended durations of observed feeding behaviour. As part of the tortoise's husbandry, the subjects had a "starve day", this was taking into consideration, the conditions, including repeats all had equal observed hours.

Experimental design

A quantitative case study approach was used to investigate if the addition of IR-A and B would affect behaviour and enclosure use amongst chelonia. The study consisted of two components: behaviour and enclosure-use observations, both of which were conducted simultaneously.



Plate 1. *A. radiata* enclosure. Basking area with UV on the left, UV in the middle and cool end to the right. Humid area situated above the hot end (Authors own, 2019).

Subjects (N= 5) were classified into two conditions, baseline (CHE) and experimental (halogen), these were then repeated for validation in an ABAB experimental design. The first condition, the baseline consisted of overhead IR-C wavelengths, whilst the second condition, the experimental stage consisted of IR-A, B and C wavelengths, this was achieved by replacing the CHE bulbs with halogen bulbs. Apart from the heating arrays, all other lighting, equipment, furnishings, and husbandry remained the same throughout the entirety of the study. The IR-C emitting bulb in the baseline experiment was positioned at 35cm from the surface, whilst the IR-A/B emitting bulb during the experimental stage, was positioned at 45cm from the surface, this allowed for a similar enclosure temperature amongst both conditions (Plate 2-5), however, a change in bulb height resulted in a basking area difference between the two conditions, this was difficult to quantify, but was attempted with a laser thermometer, it was estimated that the conditions had an area difference of +/- 8-15cm diameter; whilst this may be minimal, it may be enough of a difference to restrict the individuals from attempting to bask at the same time, especially when accounting for social hierarchies. Temperature was measured by FLIR meters (One Pro & E5) to produce a thermal image (Plate 1-5). UVI readings were also monitored by a UVI meter (ZooMed Digital UV

Index Radiometer 6.5). Visible light was measured with a digital light meter (URCERI MT-912), due to the halogen bulb emitting visible light, the basking area was brighter by an average of 300-325 LUX.

Data collection was carried out by one of the authors (NW) to avoid out of sight observations and to accurately record subtle behaviours and zone occupancy. Researcher position was semi-concealed and 3m away. Each condition/repeat was monitored for equal durations of 15 hours each, resulting in a total of 60 hours of observation.

The bulbs had a burn-in period of >100 hours prior to data collection, at the beginning of each condition, a break-in period of seven days was observed, this allowed the subjects to get accustomed to the new bulb. As a precaution, the subjects were routinely examined (remotely) to check for signs of dehydration (McArthur, Wilkinson & Meyer, 2008).

Behaviour

Instantaneous focal sampling (Martin and Bateson, 2007) was carried out at 60-second intervals for 60-minutes per observation. Ethograms were used to define behaviours (Table 4-5). Both state and event behaviours were recorded (Martin and Bateson, 2007). 12 state behaviours were identified, these were recorded using instantaneous

Table 2. Baseline Condition: UVI measurements taken 30cm from the surface, T5 12% UV bulb had measurements taken from both ends and the centre to account for UV gradients.

Lighting/heating bulbs	UVI	Avg. Surface Temperature (°C)
• 2x T5 UV 12% (Arcadia 54W)	3-4	27
• 160w active UV basking lamp	6.5	30
• 2x T5 Plant growth lights	N/A	27
• LED (Arcadia jungle dawn 22W)	N/A	27
• 2x CHE (Arcadia 150w)	N/A	36

Table 3. Experimental condition: UVI measurements taken 30cm from the surface, T5 12% UV bulb had measurements taken from both ends and the centre to account for UV gradients.

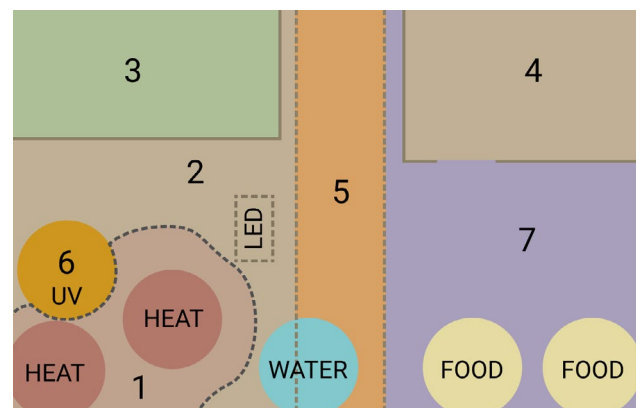
Lighting/heating bulbs	UVI	Avg. Surface Temperature (°C)
• 2x T5 UV 12% (Arcadia 54W)	3-4	27
• 160w active UV basking lamp	6.5	30
• 2x T5 plant growth lights	N/A	27
• LED (Arcadia jungle dawn 22W)	N/A	27
• 2x PAR38 Halogen (Philips 175w)	N/A	37

focal sampling method described above. Six event behaviours were chosen and recorded using continuous focal sampling (Martin & Melfi, 2016).

Enclosure usage

Enclosure use was measured by recording the location of each subject, this was achieved by dividing the enclosure into seven zones (Table 6 and Figure 3). Using the same instantaneous focal sampling method as described above, the zone occupancy of each subject was observed and recorded after each minute. Thus, presenting whether individual enclosure use is influenced by the type of infrared wavelength received. Seven zones were selected and measured

(Figure 3), these were based on a combination of resources and landmark features such as heat gradients, UV basking areas, hides and type of substrate. Zones defining locations of basking importance were calculated using laser temperature guns, FLIR meters and solarmeters, this helped to identify and outline heat gradients.

**Figure 3.** Diagram showing how the seven zones within the enclosure (Authors own & Neilson, 2020).

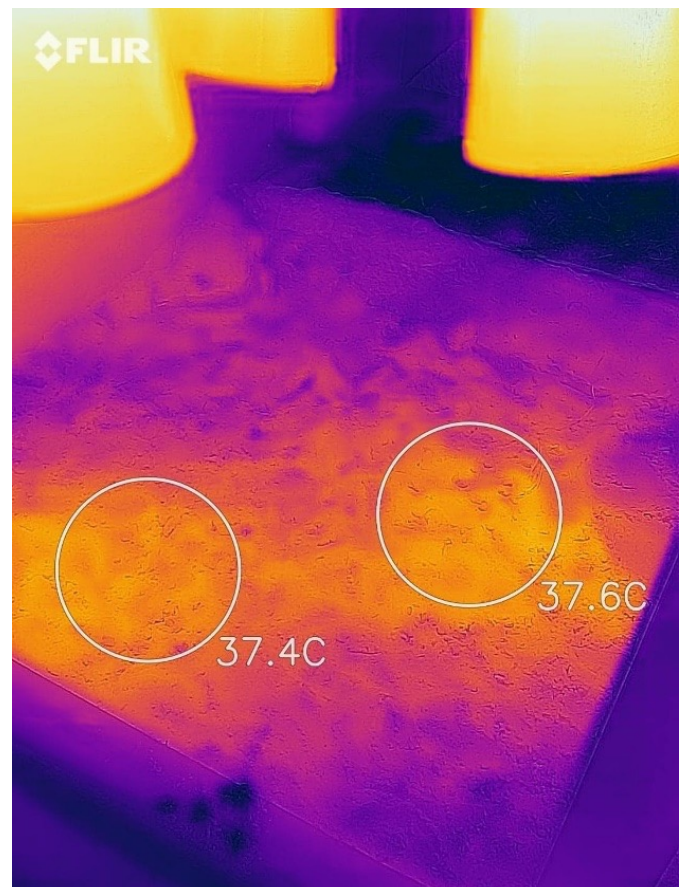
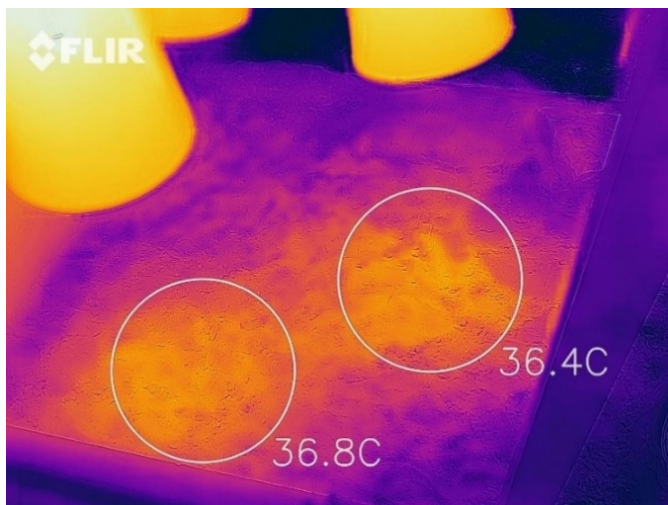


Plate 2-3. Infrared images of the basking spots (zone one) for both conditions. (above) is the baseline (right) is the experimental condition (Authors own, 2019). The CHE bulb was 150W whilst the halogen was 175W; the difference in wattage resulted in a difference in surface temperature; this was minimised by adjusting the height of the bulbs between the conditions.



Plate 4-5. Heat gradients within the enclosure, left is the baseline condition whilst right is the experimental. At the time, the ambient temperature in the room was 27°C for both conditions. (Authors own, 2019).

Table 4. *A. radiata* state behaviours.

B a s k i n g (Infrared)	Absorbing heat from either a CHE or halogen bulb via laying semi-motionless to increase metabolism rate and aid in thermoregulation. Animal is under the heat source, within the optimal basking range of >30°C (Zone 1).
Basking (UV)	Absorbing UV from a UV emitting light source via laying semi-motionless. Animal is under the light source, within the optimal UV index range of >UVI 3 (Zone 5 and 6).
Locomotion	Tortoise movement from one objective to another, using the front and hind limbs to move across the enclosure. Minimum distance was set at 5cm.
Burrowing	The tortoise uses its front claws to remove sediment to place its carapace in the cooled ditch.
Inactive	A lack of mobility for a prolonged period, >1 minute. No visible locomotion.
Feeding	The interest in a food item, followed by the consumption, mastication, and ingestion of said food item for a prolonged period, >5 seconds. May occur alongside other behaviours.
Drinking	An interest in the water bowl, followed by the using of its mandible and gullet to quench thirst from the water source. Water is imbibed through the external nares.
Climbing	Use of its front limbs to hook onto a vertical surface or another tortoise, using its hind limbs to lift the front of the carapace over a more vertical surface.
Investigating	Use of head or limbs to manipulate an object or food item.
Excretion	The release of waste products due to the digestive processes. Uric acid and faeces are expelled out through the cloaca.
Out of Sight	The tortoise has moved away from observer view, making the ability to individually identify or see the species performing a behaviour an impossibility.
Other	A state behaviour that has not featured within the list but is seen performing.

Table 5. *A. radiata* event behaviours

Biting	The use of the mandible and beak to snap at an individual, either in front of the targeted individual or catching skin or shell of the other individual in quick succession.
Jaw Snapping	The rapid closing of the mandible to the cranium, producing a cracking sound, displaying the aggression of one tortoise to another.
Bill Scraping	When a viscous substance is being removed from the jaw using the beak in an abrasive action.
Head Bobbing	When two male tortoises are competing for a mate, the neck and the skull vigorously move up and down.
Shell Bashing	The clashing of one carapace of one tortoise against another tortoise as a sign of dominance, fighting and aggression.
Other	An event behaviour not described on the ethogram.

Spread of Participation Index

To determine how *A. radiata* utilised their enclosure, a modified spread of participation index (SPI, Plowman, 2003) was conducted using the observation counts. The formula (Table 7)

was chosen over the original formula by Dickens (1995), due to it accounting for enclosures with unequal zones, such as thermal and UV gradients, and features like bodies of water (Dickens, 1955; Rose *et al.*, 2018). Modified SPI has not

Table 7. The modified SPI uses the below formula which reports a value ranging from 0 to 1. With 0 representing maximum enclosure use (i.e., all zones occupied equally) and a value of 1 indicating minimum utilisation of the enclosure (i.e., only one zone occupied).

$SPI = \frac{\sum f_o - f_e }{2(N - f_{e\min})}$	<p>f_o is the frequency of observations in a zone, f_e is the expected frequency of observations in a zone, based on zone size assuming even use of the whole enclosure, the numerator $f_o - f_e$ is the absolute value of the difference between f_o and f_e, which is summed for all zones Σ. N is the total number of observations in all zones and $f_{e\min}$ is the expected frequency of observations in the smallest zone (Rees, 2015).</p> <div style="border: 1px solid black; padding: 5px; margin: 10px auto; width: fit-content;"> <p>0 = all zones used equally 0.2 = zones used fairly equally 0.4 = zones used reasonably equally 0.6 = unequal use of zones 0.9 = very unequal use of zones 1.0 = all animals in one zone</p> </div> <p>SPI values closer to 0 indicate that the enclosure is used equally, whereas 1 indicates use of only one zone.</p>
---	---

yet been applied to reptilian or amphibian taxa, despite use in other areas (Brereton, 2020).

SPI allows keepers to analyse an enclosure based on its biological resources, helping to identify how animals best utilise their enclosure. SPI

measurements range from 0 to 1 (Table 7). SPI measurements are a useful tool to incorporate into behavioural studies and can help support behaviour data (Brereton, 2020). The tool can also help identify individual characteristics and enclosure preferences which can be useful in welfare

Table 6. Descriptions of the seven zones that were used to divide the enclosure.

Zone	Temperature °C	Zone name	Descriptor
1	30-38	Basking heat source	The area directly under the heat lamps and the surrounding area within the temperature range.
2	26-29	Open zone	Lower temperature area. Area surrounding the basking bulbs that fall outside of the basking range in zone 1. Has water.
3	21-23	Humid zone	Area of sphagnum moss: Average humidity 70%. Rocks surround the perimeter.
4	19-23	Shaded zone	Wooden box/hide with one entry point.
5	24-26	Basking zone	2x T5 bulbs at 12% with a gradient of UVI-3 at either end of the bulb and UVI-3.9 at the centre. 2x T5 grow lights. Has water.
6	27-30	Basking UV light source	160w active UV basking lamp with a UVI-6.5.
7	19-23	Rock zone	Area of open space, various rocks scatter the area. Food is located on the far right of this zone.

assessments (Quintavalle Pastorino *et al.*, 2017).

Data analysis

The data was inputted into Microsoft Excel®, descriptive statistics such as bar graphs and interval plots helped display activity budgets and enclosure use. Microsoft Excel® was also used to calculate individual SPI values per hour from the enclosure use count data; these values were averaged to represent the total individual average for each of the two conditions. Inferential statistical analysis was conducted using Minitab® 2019. The effect of the condition (baseline versus experimental) was investigated for each tortoise state behaviour, using a series of General Linear Models (GLM). The additional covariates of tortoise identity, humidity (%), and temperature (oC) were included in the model.

Poisson regressions were performed to determine the predictors of tortoise zone use for each of the seven zones. The outcome was the amount of time that tortoises spent in each zone, and the predictors included were the individual tortoise, the condition (baseline versus experimental), the temperature and humidity.

Results

Overall, there were sizeable differences in terms of tortoise behaviour between baseline and

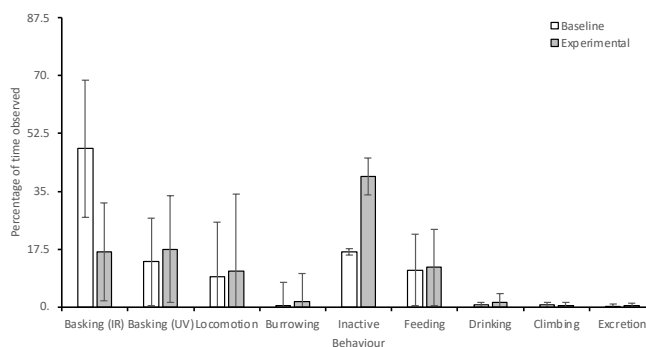


Figure 4. Activity budget for tortoise behaviour during baseline and experimental observation +/- standard error.

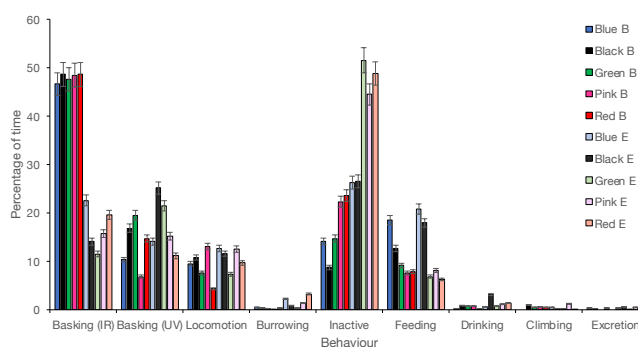


Figure 5. Activity budget of individual tortoises during baseline (B) and experimental (E) observation +/- standard error.

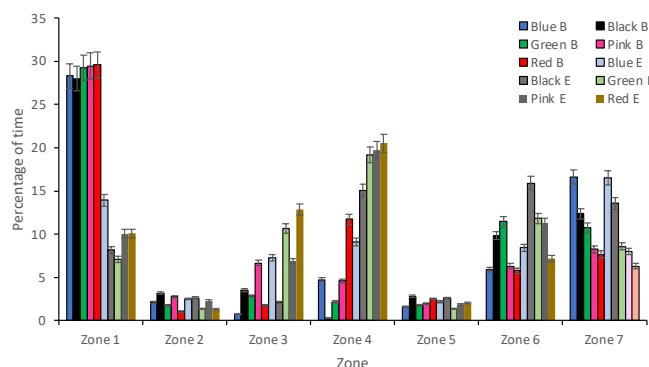


Figure 6. Zone occupancy of tortoises under baseline (B) and experimental (E) conditions +/- standard error.

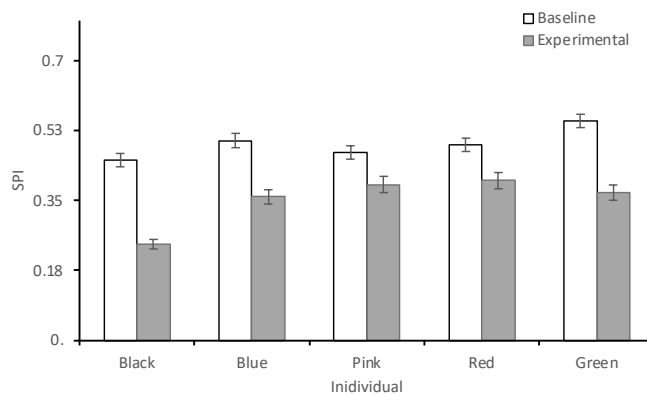


Figure 7. Spread of Participation scores for individual tortoises under baseline and experimental conditions +/- standard error.

experimental observations (Figure 4 and 5). The models for basking (IR), locomotion, inactivity, feeding, drinking, and climbing were significant. However, only Basking (IR), inactivity and drinking can possibly be attributable to the condition, as reported in the general linear model (GLM).

Zone occupancy graphs were developed to show the zone use of tortoises under both baseline and experimental conditions (Figure 6). Spread of participation scores were calculated for individual tortoises under both baseline and experimental conditions (Figure 7). Poisson regressions were run on the count data for zone use. In most cases, both the condition (baseline versus experimental) and the other predictors were significant, all except Zone 5 and zone 7.

Discussion

The study investigated whether the type of infrared wavelength provided to basking tortoises influenced their behaviour and enclosure use. Significant differences in both individual behaviour and enclosure usage were identified. Three state behaviours were significantly influenced by the condition: basking, inactivity, and drinking. A significant increase in “shell bashing” behaviour was also observed. The condition affected enclosure usage, with five out of the seven zones reporting a significant change.

Behaviour

When exposed to a halogen bulb that emitted IR-A, B and C, the subjects decreased basking behaviour by 31% ($P < 0.001$). The results support that of Thomas *et al* (2019), who reported a significant decrease in basking when varanids were exposed to a heating array with increased IR-A output. However, this study observed two conditions that shared the same UVI levels and instead focused on the addition/removal of IR-A; although visible light was different between the two conditions, this was only reported as 300-325 LUX (30 FC). Due to the enclosure being situated in a room with no windows, this reading did not fluctuate.

Whilst a decrease in basking time was observed, it is not possible to ascertain whether this was due to more efficient thermoregulation, the subjects may have simply had a preference to spending larger proportion of their time under an IR-C emitting bulb, perhaps they found the halogen bulb aversive. Future studies could possibly investigate this by implementing a preference component by installing both a CHE and a halogen bulb at either end of an enclosure, the addition of internal dataloggers could also help quantify intradermal temperatures.

A. radiata are heliothermic and diurnal, with basking occurring primarily in the early morning

(Castellano *et al.*, 2013), and other behaviours such as foraging and locomotory activity initiated once optimal activity temperatures is achieved (Rose & Judd, 2014; Ernst & Lovich, 2009). In contrast, it appeared that when exposed to the IR-C emitting bulbs, tortoises may have not achieved optimal intradermal temperatures, supported by the fact that subjects spent a larger percentage of time basking. Meek (1984) reports that Hermann's tortoises (*Testudo hermanni*) display increased activity when internal body temperatures of 34-35°C are reached, basking duration is increased in cloudy conditions and reduced in summer; a strategy which has also been observed in the Greek tortoise (*Testudo graeca graeca*, Meek and Jayes, 1982).

A reduction in basking time may be beneficial to ectotherms; central bearded dragons (*Pogona vitticeps*) have been observed to actively reduce basking duration by utilising adaptive skin colouration to increase IR absorption (Smith *et al.*, 2016; Vitt & Caldwell, 2014). The benefits of a reduction in basking behaviour can include extra time to forage, mate and to potentially reduce the time spent out in the open (Meek, 1995; 1988). By hastening thermoregulation, computer modelling predicts that *P. vitticeps* save approximately 85 hours during the energy-intensive breeding season (Smith *et al.*, 2016). Currylow *et al* (2017) shed

some light on wild, free-ranging *A. radiata* activity by conducting behavioural observations over a duration of 22 months; interestingly, the findings report that basking contributes to just 3.5% of their daily budgets, suggesting that reducing basking times is important for replicating wild behaviour. Literature, both peer reviewed and anecdotal could not be sourced regarding captive energy budgets for *A. radiata*, however, a wild versus captive budget was found for the angonoka (*A. yniphora*) (Currylow *et al.*, 2017). The study identified that basking duration between wild and captive *A. yniphora* were 1% and 7% respectively, indicating that captive animals may spend larger percentage of time basking.

Due to a significant reduction in basking (IR) behaviour, subjects exposed to the halogen bulb had extra time within their activity budget to execute other behaviours, with this extra time allocation, the five individuals increase inactivity levels by 137%. Inactivity could be interpreted as sleeping, relaxing, digesting, or perhaps lack of stimulation. Despite this, wild *A. radiata* and *A. yniphora* are known to spend a large proportion of their time being inactive, often including periods of up to four days (Currylow, Louis & Crocker, 2017; Paquette *et al.*, 2006). Wild *A. radiata* activity budgets conducted by Currylow *et al* (2017) report that "resting" behaviour contributes towards 61-76% of

tortoise's daily budget; and that wild *A. yniphora* resting behaviour accounted for 85% and around 70% in captivity. Prior studies amongst other Genus help further support the theory that a high percentage of inactivity may be a natural chelonian behaviour; Greek tortoises (*T. graeca graeca*) 93%, Russian tortoise (*Agrionemys horsfieldi*) >90% and desert tortoise (*Gopherus agassizii*) >90% (Lagarde *et al.*, 2008; Lagarde *et al.*, 2003).

The only behaviours which were found to be purely influenced by IR wavelengths were Basking (IR) and drinking. The predictor "humidity" appeared to be solely responsible for significance found within tortoise locomotion; this was also identified within captive *A. yniphora* in Madagascar, the animals walked more often in higher humidity ground conditions ($75.0 \pm 1.9\%$).

A significant increase ($p < 0.001$) in shell bashing was reported for tortoises exposed to the halogen bulb, however, a low effect size ($r = 0.033$) implies low variation between the conditions. Interestingly, 86% of shell bashing behaviour was observed between the two males, this could be considered as increased aggression towards conspecifics, notably towards the same sex, it is not known why this was observed. The males may have had more energy to display agonistic behaviour, either

for female competition or for priority basking resource rights; due to the increased height of the halogen bulb condition, the basking size could have been smaller, resulting in resource competition.

All five subjects were observed spending similar basking durations during the CHE condition ($\pm 2\%$), however, basking duration began to vary between individuals when the subjects were exposed to the halogen bulb. Subject "black" spent a large proportion of his time basking in the halogen condition (14%), this was originally assumed to be due to his size and thus needing more time to effectively reach a comfortable optimal temperature, however, the largest tortoise, subject "green", was observed spending the least amount of time basking (7%), suggesting that in this study, basking duration cannot be explained by weight or sex. Subject "Black" was the darkest tortoise amongst the subjects, with a carapace containing very little yellow/orange pigmentation, primarily being black. It was theorised that due to this, energy absorbency would be hastened, resulting in a shorter basking duration being required, a theory derived from simple physical principles (Rice and Bradshaw, 1980), however, the opposite was observed. Subject "black" had the highest IR basking budget compared to other tortoises: it is unclear this individual spent such a large proportion of time basking.

Enclosure usage

While individual differences in enclosure use were observed (Figure 7), these were often non-significant. The tortoises tended to change their enclosure use in similar ways in response to the experimental condition. In the IR-A and B condition, tortoises spent 19% more time in zone four (sheltered refugia). The primary behaviour that tortoises were exhibiting in zone four was inactivity. The behavioural study conducted by Currylow *et al.* (2017) also included location data, the findings report that wild *A. radiata* spend on average, 25.5% of their activity budget resting whilst under shelter, this value is close to the experimental condition value for zone four (27%). This similarity may possibly indicate that tortoises exposed to IR-A and B wavelengths are expressing more natural enclosure use. Sheltered refugia is an important resource for effective thermoregulation (Rasoma *et al.*, 2013), they can act as a microclimate allowing herptiles to optimise energy expenditure through behavioural variation (Huey & Tewksbury, 2009), additionally, they can provide animals with security, potentially helping with predator avoidance, which may potentially reduce animal stress. A stress measurement component would be an interesting future study regarding IR heating provisions. The subjects spent more time within the moist/

humid area (zone three) when exposed to the halogen condition. The choice in zone use may have been a thermoregulatory strategy in response to increased intradermal temperature, this theory may also explain the extended use of the sheltered refugia. Though non-significant, increased burrowing behaviour was also observed, this may have been attributable to thermoregulatory behaviour, a response that is reported amongst Testudines species, including *A. radiata* (Wilson, Nagy, Tracy, Morafka & Yates, 2001).

A modified SPI reported that all five tortoises utilised their enclosure more evenly when exposed to the halogen bulb (Figure 7), this could be attributed to the fact that the tortoises were more active from an increased internal temperature and were utilising the enclosure more, specifically the humid, sheltered and drinking zones for thermoregulation. It was evident that zones two and five were underutilised and were unaffected by the type of heating array. Zone five was a secondary UV basking resource situated within the middle of the enclosure; this zone had a reduced UVI output in comparison to the more favoured UV basking resource in zone six. It is a possibility that the tortoises had a preference over a stronger UVI or may have preferred basking in a zone with a higher ambient basking temperature. The results may suggest the necessity to enhance the

underutilised areas with more fitting biologically relevant or enriching structures that can potentially induce the subjects to use them (Brereton, 2020).

Use within captivity

The provision of IR-A and B wavelengths to herptiles could be double-edged, whilst it may have beneficial welfare applications, it also may have some unfavourable consequences. Visitors attend zoological institutions to view animals and this study suggests that the lights may increase inactivity (Roe, McConney & Mansfield, 2014). Additionally, increased aggressive behaviours that may potentially be caused by IR-A and B, may increase the chance and risk of injuries for species housed within communal enclosures. These attributes are unattractive qualities for captive animals to exhibit, ones that keepers actively try to discourage. However, this needs to be balanced against the fact, that as professionals and welfare advocates, it is important to encourage and replicate natural behaviours where possible (Hosey, Melfi & Pankhurst, 2013).

This study is not suggesting that IR-C emitting arrays such as CHE should be abandoned, they remain an essential lighting choice for night-time heating. When the Sun sets, IR-A and B are no longer being emitted, however, surfaces around 30-100°C that have received IR-A lighting during the day do emit

IR-C, a significant amount of this heat is transferred to the surrounding via conduction (Wunderlich, personal communication, 2020); IR-C energy can be released for long periods of time, hence the reason why there is not a sudden temperature drop after dark (Jones, 2018). This makes IR-C heating arrays a good night-time solution for replicating natural heating after dark (Courtney-Smith, 2018).

Future directions

The findings of this study demonstrate that the provision of IR-A and B lighting may have been responsible for a significant effect on reptile behaviour and enclosure usage. The findings may however be due to the time window in which data was collected, it is a possibility that basking and other behaviours occurred earlier in the morning, prior to observation. Data collection occurred between the hours of 1100-1600, thus activity budgets were not full 24-hour representation. Future studies could address this by monitoring morning, afternoon, and evening observation points such as implemented by Thomas *et al* (2019).

The power output between the bulbs was not ideal (150W vs 175W), this resulted in the conditions having different basking temperatures and height, which affected basking area size. Best efforts were made to minimize both variables, however,

these were still evident. At the time of the study, a PAR 38 150W Halogen flood bulb could not be sourced, if repeated, this should be addressed, and uniformity of wattage should be a priority.

Conclusion

IR-A and B emitting bulbs may allow captive reptiles to express behaviours that are not commonly observed by either A) having more energy and B) having more free time within the activity budget to express certain behaviours. Based on wild activity budgets and enclosure use studies, to better replicate *A. radiata* natural behaviour, reduced basking durations, increased inactivity and prolonged shelter use should be further encouraged within captivity, the findings of this study appear to show that by providing natural bioavailable heat in the form of IR-A and B, this could potentially be accomplished. The concept of promoting natural behaviour is a key element in current policymaking on animal welfare, as such, it is an area that demands further research. The answer to the question of whether IR-A and B emitting arrays are beneficial for captive herptiles is unfortunately out of scope for this paper, however, IR-A and B provision is a progressive area of study within the field of reptile husbandry, as such, it warrants extensive consideration and research. This will help aid in the advancement of captive welfare and the development of husbandry guidelines.

Acknowledgments

The authors would like to thank Sparsholt College, Winchester, and the AMC staff; Mr G Miller, Ms E Lawson, and Mr T Starkey for providing the animals and accommodating the research. Finally, special thanks to Dr. F Baines, Dr. S Wunderlich and Mr R Muryr for their support and assistance with the project.

References

- Aly, E., & Mohamed, E. (2011) Effect of infrared radiation on the lens. *Indian Journal Of Ophthalmology* 59: 97. doi: 10.4103/0301-4738.77010
- ASAB. (2017) Guidelines for the treatment of animals in behavioural research and teaching. *Animal Behaviour* 135: 1-10. doi: 10.1016/j.anbehav.2017.10.001
- Baines, F., Chattel, J., Dale, J., Garrick, D., Gill, I., Goetz, M. Skelton, T., Swatman, M. (2016) How much UV-B does my reptile need? The UV-Tool, a guide to the selection of UV lighting for reptiles and amphibians in captivity. *Journal of Zoo and Aquarium Research* 4: 42-63. <http://orcid.org/0000-0002-8063-6134>
- Ballantyne, R., Packer, J. (2016) Visitors'

- Perceptions of the Conservation Education Role of Zoos and Aquariums: Implications for the Provision of Learning Experiences. *Visitor Studies* 19: 193-210. doi: 10.1080/10645578.2016.1220185
- Barolet, D., Christiaens, F., Hamblin, M. (2016) Infrared and skin: Friend or foe. *Journal Of Photochemistry And Photobiology B: Biology* 155: 78-85. doi: 10.1016/j.jphotobiol.2015.12.014
- Beaupre, S.J. Zaidan, F. (2012) Digestive performance in the timber rattlesnake (*Crotalus horridus*) with reference to temperature dependence and bioenergetic cost of growth. *Journal of Herpetology* 46: 637-643.
- Brereton, J.E (2020) Current directions in animal enclosure use studies. *Journal of Zoo and Aquarium Research* 8: 1-7. doi: 10.19227/jzar.v8i1.330
- Brown, D., Picot, P., Gharavi Naeini, J., Springett, R., Delpy, D., Lee, T. (2002) Quantitative Near Infrared Spectroscopy Measurement of Cerebral Hemodynamics in Newborn Piglets. *Pediatric Research* 51: 564-570. doi: 10.1203/00006450-200205000-00004
- Castellano, C., Rhodin, A., Ogle, M., Mittermeier, R., Randriamahazo, H., Hudson, R., Lewis, R. (2013) Turtles on The Brink in Madagascar [Ebook] (6th ed., p. 62). Lunenburg: Chelonian Research Foundation.
- Cho, S., Shin, M., Kim, Y., Seo, J., Lee, Y., Park, C., & Chung, J. (2009) Effects of Infrared Radiation and Heat on Human Skin Aging in vivo. *Journal Of Investigative Dermatology Symposium Proceedings* 14: 15-19. doi: 10.1038/jidsymp.2009.7
- Chung, H., Dai, T., Sharma, S., Huang, Y., Carroll, J., Hamblin, M. (2011) The Nuts and Bolts of Low-level Laser (Light) Therapy. *Annals of Biomedical Engineering* 40: 516-533. doi: 10.1007/s10439-011-0454-7
- Courtney-Smith, J. (2018) The sun. Monkfield, Cambridge, UK. 123-131 pp.
- Cowles, E., Kovar, J., Curtis, E., Xu, H., Othman, S. (2013) Near-Infrared Optical Imaging for Monitoring the Regeneration of Osteogenic Tissue-Engineered Constructs. *BioResearch Open Access* 2: 186-191. doi: 10.1089/biores.2013.0005
- Currylow, A., Louis, E., Crocker, D. (2017) Stress response to handling is short lived but may reflect personalities in a wild, Critically Endangered tortoise species. *Conservation Physiology* 5: 1-10

doi: 10.1093/conphys/cox008

Currylow, A., Mandimbihasina, A., Gibbons, P., Bekarany, E., Stanford, C., Louis, E., & Crocker, D. (2017) Comparative ecophysiology of a critically endangered (CR) ectotherm: Implications for conservation management. *PLOS ONE* 12: doi: 10.1371/journal.pone.0182004

Currà, A., Gasbarrone, R., Cardillo, A., Trompetto, C., Fattapposta, F., Pierelli, F. (2019) Near-infrared spectroscopy as a tool for in vivo analysis of human muscles. *Scientific Reports* 9: 274-276. doi: 10.1038/s41598-019-44896-8

De Vosjoli, P. (2012) The lizard keeper's handbook. BowTie Inc, Santee, California, USA, 94 pp.

Dickens, M. (1955) A statistical formula to quantify the "spread of participation" in group discussion. *Speech Monographs* 22: 28-30. doi: 10.1080/03637755509375128

Divers, S., & Stahl, S. (2019) Mader's reptile and amphibian medicine and surgery. 3rd edition. Saunders, China. 75-79 pp.

Doody, J., Castellano, C., Rakotondrainy, R., Ronto, W., Rakotondriamanga, T., Duchene, J.,

Randria, Z. (2011) Aggregated Drinking Behavior of Radiated Tortoises (*Astrochelys radiata*) in Arid Southwestern Madagascar. *Chelonian Conservation and Biology* 10: 145-146. doi: 10.2744/ccb-0850.1

Ernst, C., Lovich, J. (2009) Turtles of the United States and Canada. John Hopkins University Press, Baltimore, USA. 582 pp.

He, H., Chen, J. (2012) Educational and enjoyment benefits of visitor education centres at botanical gardens. *Biological Conservation* 149: 103-112. doi: 10.1016/j.biocon.2012.01.048

Highfield, A. (2015) Effect of Basking Lamps on the Health of Captive tortoises and other reptiles. Retrieved 10 March 2020, from <http://www.tortoisetrust.org/articles/baskinghealth.html>

Hosey, G., Melfi, V., & Pankhurst, S. (2013) Zoo animals (2nd ed., p. 255). Oxford: Oxford University Press.

Huey, R., Tewksbury, J. (2009) Can behavior douse the fire of climate warming? *Proceedings Of The National Academy of Sciences* 106: 3647-3648. doi: 10.1073/pnas.0900934106

Jones, A. (2018) Infrared Wavelengths and Reptile

- Care - Arcadia Reptile. Retrieved from <https://www.arcadiareptile.com/infrared-wavelengths-and-reptile-care/>
- Lagarde, F., Bonnet, X., Corbin, J., Henen, B., Nagy, K., Mardonov, B., Naulleau, G. (2003) Foraging behaviour and diet of an ectothermic herbivore: *Testudo horsfieldi*. *Ecography* 26: 236-242. doi: 10.1034/j.1600-0587.2003.03365.x
- Lagarde, F., Guillon, M., Dubroca, L., Bonnet, X., Ben Kaddour, K., Slimani, T., El mouden, E. (2008) Slowness and acceleration: a new method to quantify the activity budget of chelonians. *Animal Behaviour* 75: 319-329. doi: 10.1016/j.anbehav.2007.01.010
- Lappin, A., Brandt, Y., Husak, J., Macedonia, J., Kemp, D. (2006) Gaping Displays Reveal and Amplify a Mechanically Based Index of Weapon Performance. *The American Naturalist* 168: 100-113. doi: 10.1086/505161
- Leuteritz, T. (2003) Observations on diet and drinking behaviour of radiated tortoises (*Geochelone radiata*) in Southwest Madagascar. *African Journal of Herpetology* 52: 127-130. doi: 10.1080/21564574.2003.9635490
- Lopes, C., Pacheco, M., Silveira, L., Duarte, J., Cangussú, M., Pinheiro, A. (2007) The effect of the association of NIR laser therapy BMPs, and guided bone regeneration on tibial fractures treated with wire osteosynthesis: Raman spectroscopy study. *Journal of Photochemistry and Photobiology B: Biology* 89: 125-130. doi: 10.1016/j.jphotobiol.2007.09.011
- Martin, P., Bateson, P. (2017) Measuring behaviour. 2nd edition. Cambridge University Press, Cambridge, UK. 74-80 pp.
- Martin, R., Melfi, V. (2016) A Comparison of Zoo Animal Behavior in the Presence of Familiar and Unfamiliar People. *Journal of Applied Animal Welfare Science* 19: 234-244. doi: 10.1080/10888705.2015.1129907
- McArthur, S., Wilkinson, R., & Meyer, J. (2008) *Medicine and Surgery of Tortoises and Turtles*. John Wiley & Sons, New York, USA. 271 pp.
- Meek, R. (1995) Reptiles, thermoregulation, and the environment. British Chelonia Group, Huddersfield, UK. 56-78 pp.
- Meek, R. and Avery, R.A. (1988) Thermoregulation in chelonians. *Herpetological Journal* 1,253-259 pp.

- Meek, R. (1984). Thermoregulatory behaviour in a population of Hermann's tortoise (*Testudo hermanni*) in southern Yugoslavia. *British Journal of Herpetology* 6, 387-391 pp.
- Meek, R. and Jayes, A.S. (1982) Body temperatures and activity patterns of *Testudo graeca* in North West Africa. *British Journal of Herpetology* 6, 194-197 pp.
- Michaels, C.J., Downie, J.R. Campbell-Palmer, R. (2014) The importance of enrichment for advancing amphibian welfare and conservation goals. *Amphibian Reptile Conservation* 8: 7-23.
- Min, P., Goo, B. (2013) 830 nm light-emitting diode low level light therapy (LED-LLLT) enhances wound healing: a preliminary study. *Laser Therapy* 22: 43-49. doi: 10.5978/islsm.13-or-06
- Paquette, S., Behncke, S., O'Brien, S., Brenneman, R., Louis, E., Lapointe, F. (2006) Riverbeds demarcate distinct conservation units of the radiated tortoise (*Geochelone radiata*) in southern Madagascar. *Conservation Genetics* 8: 797-807. doi: 10.1007/s10592-006-9227-5
- Plowman, A. (2003) A note on a modification of the spread of participation index allowing for unequal zones. *Applied Animal Behaviour Science* 83: 331-336. doi: 10.1016/s0168-1591(03)00142-4
- Porter, W. (1967) Solar Radiation through the Living Body Walls of Vertebrates with Emphasis on Desert Reptiles. *Ecological Monographs* 37(4): 273-296.
- Quintavalle Pastorino, G., Viau, A., Curone, G., Pearce-Kelly, P., Faustini, M., Vigo, D. (2017) Role of Personality in Behavioral Responses to New Environments in Captive Asiatic Lions (*Panthera leo persica*). *Veterinary Medicine International* 2017: 1-17. doi: 10.1155/2017/6585380
- Rasoma, R., Raselimanana, A., Ratovonamana, Y., Ganzhorn, J. (2013) Habitat Use and Diet of *Astrochelys radiata* in the Subarid Zone of Southern Madagascar. *Chelonian Conservation and Biology* 12(1), 56-69. doi: 10.2744/ccb-0909.1
- Rees, P. (2015) Studying captive animals. Wiley-Blackwell, Chichester, UK. 167 pp.
- Reptile Lighting Guide. (2017) 1st ed. [ebook] Canada: Hagan, p.8. Available at: http://www.hagan.com/pdf/reptiles/Exo_Terra_Lighting_Guide_EN.pdf
- Rice, G. and Bradshaw, S. (1980) Changes in

- dermal reflectance and vascularity and their effects on thermoregulation in *Amphibolurus nuchalis* (reptilia: Agamidae). *Journal of Comparative Physiology* 135(2): 139-146.
- Roe, K., McConney, A., Mansfield, C. (2014) The Role of Zoos in Modern Society—A Comparison of Zoos' Reported Priorities and What Visitors Believe They Should Be. *Anthrozoös* 27: 529-541. doi: 10.2752/089279314x14072268687808
- Rose, F., Judd, F. (2014). The Texas tortoise. University of Oklahoma Press, Oklahoma, USA.
- Rose, P.E., Brereton, J.E., Croft, D. (2018) Measuring welfare in captive flamingos: Activity patterns and exhibit usage in zoo-housed birds. *Applied Animal Behaviour Science* 205: 115-125. doi: 10.1016/j.applanim.2018.05.015
- Ruggiero, E., Alonso-de Castro, S., Habtemariam, A., & Salassa, L. (2016) Upconverting nanoparticles for the near infrared photoactivation of transition metal complexes: new opportunities and challenges in medicinal inorganic photochemistry. *Dalton Transactions*, 45: 13012-13020. doi: 10.1039/c6dt01428c
- Schieke, S., Schroeder, P., Krutmann, J. (2003) Cutaneous effects of infrared radiation: from clinical observations to molecular response mechanisms. *Photodermatology, Photoimmunology And Photomedicine* 19: 228-234. doi: 10.1034/j.1600-0781.2003.00054.x
- Schroeder, P., Haendeler, J., Krutmann, J. (2008) The role of near infrared radiation in photoaging of the skin. *Experimental Gerontology* 43: 629-632. doi: 10.1016/j.exger.2008.04.010
- Smith, K., Cadena, V., Endler, J., Porter, W., Kearney, M., Stuart-Fox, D. (2016) Colour change on different body regions provides thermal and signalling advantages in bearded dragon lizards. *Proceedings of The Royal Society B: Biological Sciences* 283: 20160626. doi: 10.1098/rspb.2016.0626
- Sowa, P., Rutkowska-Talipska, J., Rutkowski, K., Koszyła-Hojna, B., Rutkowski, R. (2013) Optical radiation in modern medicine. *Advances In Dermatology And Allergology* 4: 246-251. doi: 10.5114/pdia.2013.37035
- Thomas, O. (2019) Effects of different heat sources on the behaviour of blue tree monitors (*Varanus macraei*) in captivity. *Herpetological Bulletin* 149: 41-43. doi: 10.33256/hb149.4143

Vitt, L., Caldwell, J. (2014) *Herpetology*. 4th ed. Elsevier, Amsterdam, Netherlands. 257 pp.

Wilson, D., Nagy, K., Tracy, C., Morafka, D., Yates, R. (2001): Water Balance in Neonate and Juvenile Desert Tortoises, *Gopherus agassizii*. *Herpetological Monographs* 15: 158. doi: 10.2307/1467042