Moore, H.A., Champney, J.L., Dunlop, J.A., Valentine, L.E., Nimmo, D.G. (2020) Spot on: using camera traps to individually monitor one of the world's largest lizards. *Wildlife Research,* Vol. 47, Iss. 4, 326-337.

DOI: https://doi.org/10.1071/WR19159

Spot on: Using camera traps to individually monitor one of the world's largest lizards

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Manuscript published:
Moore, H., Champney, J., Dunlop, J., Valentine, L., and Nimmo, D. (2020). Spot on: Using camera traps to individually monitor one of the world's largest lizards. *Wildlife research* **47**, 326-337.

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Article type: Research paper

ABSTRACT

Context

Estimating animal abundance often relies on being able to identify individuals, but this can be challenging, especially when applied to large animals which are difficult to trap and handle. Camera traps have provided a non-invasive alternative by using natural markings to individually identify animals within image data. While camera traps have been used to individually identify mammals, they are yet to be widely applied to other taxa, such as reptiles.

Aims

We assessed the capacity of camera traps to provide images that allow for individual identification of the world's fourth largest lizard species, the perentie (*Varanus giganteus*), and demonstrate other basic morphological and behavioural data that can be gleaned from camera trap images.

Methods

Vertically orientated cameras were deployed at 115 sites across a 10,000km^2 area in north-west Australia for an average of 216 days. We used spot patterning located on the dorsal surface of perenties to identify individuals from camera trap imagery, with the assistance of freely available spot ID software. We also measured snout-to-vent length (SVL) using image analysis software, and collected image time stamp data to analyse temporal activity patterns.

Results

Ninety-two individuals were identified, and individuals were recorded moving distances of up to 1975m. Confidence in identification accuracy was generally high (91%), and estimated SVL measurements varied by an average of 6.7% (min = 1.8%, max = 21.3%) of individual SVL averages. Larger perentie (SVL > 45cm) were detected mostly between dawn and noon and in the late afternoon and early evening, whereas small perentie (SVL < 30cm) were rarely recorded in the evening.

Conclusions

Camera traps can be used to individually identify large reptiles with unique markings, and can also provide data on movement, morphology, and temporal activity. Accounting for uneven substrates under cameras could improve the accuracy of morphological estimates. Given that camera traps struggle to detect small, nocturnal reptiles, further research is required to examine whether cameras miss smaller individuals in the late afternoon and evening.

Implications

Camera traps are increasingly being used to monitor reptile species. The ability to individually identify animals provides another tool for herpetological research worldwide.

Introduction

Estimating species' abundance remains a key challenge within ecology and conservation biology (Volkov *et al.* 2003). One obstacle is the need to distinguish between individuals within a population in order to derive abundance estimates (Silver *et al.* 2004). For instance, mark-recapture analysis has traditionally required trapping and individually marking an animal, and then using the number of re-traps to estimate species density and abundance (Pradel 1996). However, physically capturing animals is not always practical (Sanecki and Green 2005) nor desirable (De Bondi *et al.* 2010), and therefore non-invasive methods that use unique morphological features to passively identify individuals are sometimes more appropriate (Brooks *et al.* 2010; Silver *et al.* 2004).

Camera traps provide a means of collecting image-based data that can be used to distinguish marked (scaring, natural markings) individuals from one another (Foster and Harmsen 2012; Higashide *et al.* 2012), and are increasingly used to estimate species density/abundance using mark-recapture analysis (Burton *et al.* 2015). So far, studies that have used camera trap imagery to identify individual animals and estimate density/abundance have been almost entirely limited to mammalian taxa (Burton *et al.* 2015), such as tigers (*Panthera tigris*)(Jhala *et al.* 2011), bobcats (*Lynx rufus*) (Alonso *et al.* 2015), leopards (*Panthera pardus*) (Rostro-García *et al.* 2018) and puma (*Puma concolor*)(Alexander and Gese 2018). Despite increasing recognition that camera traps provide a useful method with which to survey reptiles (Molyneux *et al.* 2018; Richardson *et al.* 2018; Welbourne *et al.* 2015; Welbourne *et al.* 2017), few studies have used camera trap imagery to identify individuals within a reptile species (Bennett and Clements 2014; Welbourne 2013), although other studies have identified individuals using manually operated cameras (Kellner *et al.* 2017; Moro and MacAulay 2014; Treilibs *et al.* 2016).

Species within the predatory lizard genus Varanus are notoriously difficult to trap and handle (Green and King 1978; Jessop *et al.* 2006), given they can weigh >90kg and measure three metres in length (Jessop *et al.* 2006), and yet the need to monitor these species has never been greater. Varanids (*Varanus.spp*) are widely distributed across Australia, Asia and Africa, and often fulfil the role of a mesopredator or apex predator (King and Green 1999). Multiple species of varanids are threatened from exploitation by humans (meat, leather) (Shine and Harlow 1998), the illegal pet trade (Ruxmoore and Groombridge 1990), habitat loss (Gibbons *et al.* 2000) and introduced species (Shine 2010). The removal of these important predators from ecosystems can have cascading impacts on a range of other species (Doody *et al.* 2006; Read and Scoleri 2015; Sutherland *et al.* 2010), highlighting the need for a more accurate understanding of their populations.

Here, we use camera trap imagery to identify individuals of the world's fourth largest species of lizard, the Perentie (*Varanus giganteus).* Perentie measure in excess of 2 m long, weigh up 20 kg, and are potentially venomous (Fry *et al.* 2006; Wilson and Swan 2017), however little is known about the ecology of this species. The use of non-capture methods to study perentie are therefore particularly desirable, especially given trapping these animals likely poses risks to both the animal and the handler. Further, their large size means that perentie tend to evade capture/detection using traditional reptile survey techniques such as pitfall trapping (Richardson *et al.* 2018). The scales of perentie are covered with lateral bands of large yellow spots that are unique to the individual (Moro and MacAulay 2014). In this study, we investigate the feasibility of individually identifying perentie at a landscape-scale using remote sensing cameras. We also use scaled camera trap images to estimate individual body lengths, and time stamp data to observe temporal trends — both techniques which have never been used on a varanid species and are very rarely applied to reptiles in general.

Methods

Study site

This study was conducted across four cattle stations within the Pilbara bioregion in north-west Australia. This area also encompassed the Karayarra and Nyamal indigenous language groups (Fig B1). Vegetation within this area is mostly dominated by *Triodia* grasslands (McKenzie *et al.* 2009). Geology in the Pilbara is characterised by largely flat sand plains and granite outcrops (Doughty *et al.* 2011; Withers 2000). Average annual rainfall within the study area is 339.5mm (Indee station) (BOM 2020).

Survey design

We used a whole-of-landscape experimental design, in which multiple sample sites are embedded within a heterogeneous area (Fahrig 2003), commonly termed a landscape (Bennett *et al.* 2006). Twenty three study landscapes were selected using ArcMap 10.3 (ESRI 2011). In our study, landscapes were circular with a diameter of 1 km (area =75 ha), and were selected to contain patches of rocky habitat dispersed within a matrix of spinifex grasslands. We deployed five camera sites within each landscape (115 sites in total), each separated by > 200 meters. All study sites were placed within rocky outcrops, as this habitat is known to be utilized by perenties and other species (e.g., northern quolls, *Dasyurus hallucatus*) that were the focus of the broader research program within which this study was embedded (Menkhorst and Knight 2001; Wilson and Swan 2017).

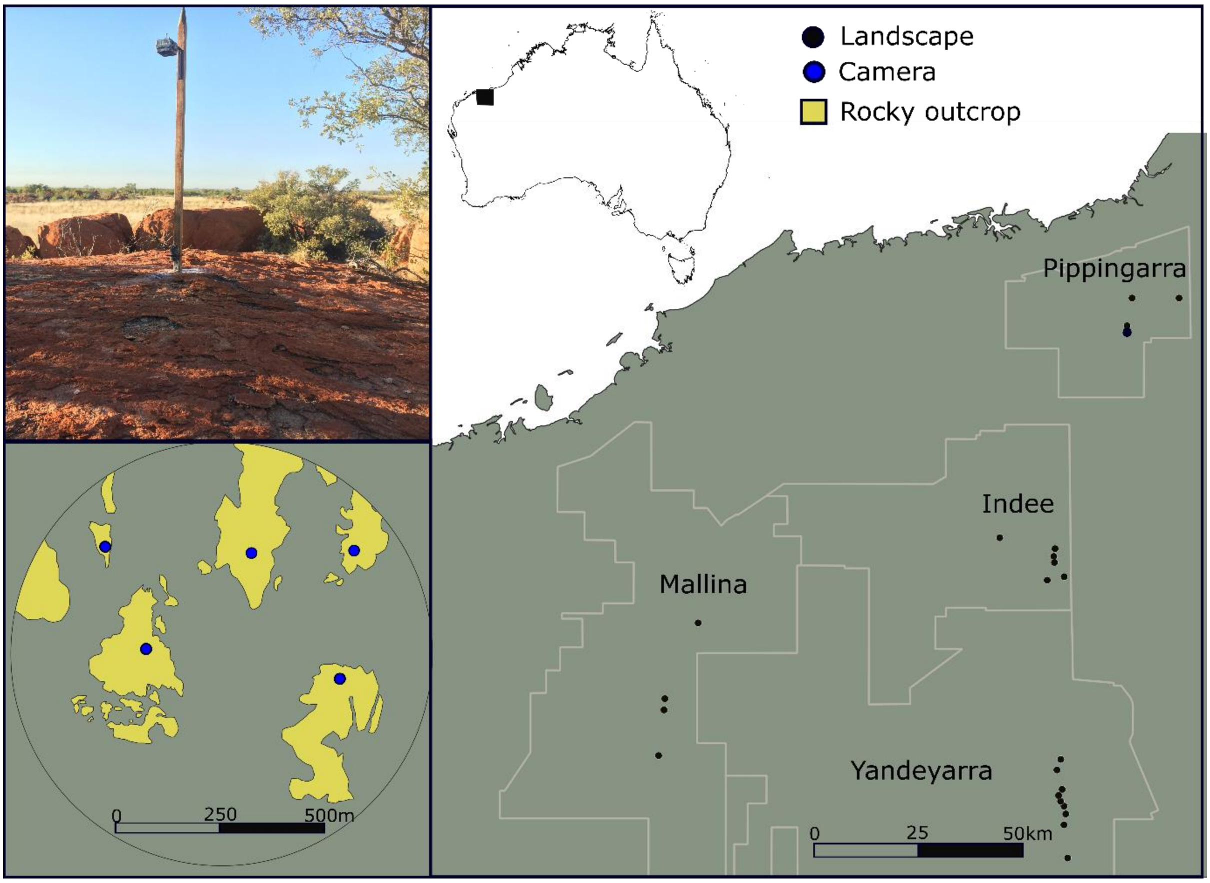

Figure B1 – Twenty three study landscapes spread across four cattle stations in the Pilbara bioregion — Pippingarra, Indee, Yandeyarra and Mallina. Grey lines represent cattle station boundaries. Five downward facing camera sites were deployed at each study landscape.

We used Reconyx™ PC900 Hyperfire covert cameras (Reconyx , Wisconsin, USA). These cameras use an infrared flash. Cameras were attached to a wooden tree stake 1.5m above the ground and were positioned to face downward, with the camera lens focused directly at the ground surface using a bookshelf bracket (Appendix 1). A PVC canister containing approximately 150g of bait (canned fish) was attached to the bottom of the tree stake supporting the camera. Twelve landscapes were sampled between August 2017 and April 2018. The remaining 11 landscapes were sampled between August 2018 and April 2019. Average camera deployment time was 216 (min =151, max = 245) days at each site. Bait was replenished twice at all sites during this period after roughly 70 and 140 days of camera deployment.At yandeyarra station, camera placement was partly guided by knowledge from Indigenous rangers as part of the Greening Australia ranger program. Cameras were set to high sensitivity with no delays between triggers, and five images were taken at one second intervals per trigger. We defined an independent detection event as consecutive triggers of the same individual separated by greater than 15 minutes.

Individual identification

We used spot patterning located on the dorsal surface of perentie to identify individuals from camera trap imagery (Figure B2). To do this, we first catalogued images from each detection event that best represented an individual's unique spot pattern. Only images with at least 30% of the animal's dorsal surface patterning visible were catalogued for analysis. We found that attempting to identify animals in images with less than 30% of the animal's dorsal surface viable was generally unreliable, as fewer spots markings are available to distinguish between animals.

We then entered one or more images from each catalogued detection event into I3S (Den Hartog and Reijns 2016) —a freely available spot ID program that has previously been used to identify individuals in other spotted species such as spotted eagle rays (*Aetobatus narinari*) (Cerutti-Pereyra *et al.* 2018), Italian crested newts (*Triturus carnifex*) (Sannolo *et al.* 2016) and whale sharks (*Rhincodon typus*) (Rowat *et al.* 2009). I3S automatically compares a target individual's spot pattern to a library of other individual spot patterns that have been pre-entered into the system by an observer. To do this, the I3S uses a two-dimensional linear algorithm, which compares spot coordinates, as well as spot shape and size between patterns. I3S then ranks which patterns within the existing library are most similar to the target spot pattern in the form of a pattern difference score, where lower pattern difference scores correspond to increasing pattern similarity (Cerutti-Pereyra *et al.* 2018; Speed *et al.* 2007). Once patterns had been ranked, at least two observers manually confirmed if the pattern suggested by the I3S program matched the target spot pattern. If no match could be found, the target individual was assigned a reference code and entered into the data base as a new animal.

To gauge observer confidence in individual identification accuracy, we marked each detection event with a confidence rating using an adapted identification protocol outlined in (Hohnen *et al.* 2013). Confidence rating were derived from the number of unique markings/features that could used to identify an animal. An observer had 'high' confidence that an individual has been accurately identified if at least five unique markings/features could be used to identify an animal. An observer had 'medium' confidence that an individual has been accurately identified if between two and five markings/features could be used to identify an animal. An observer had 'low' confidence that an individual has been accurately identified if only one marking/feature could be used to identify an animal. For individuals that were recorded at more than one site, we measured distance travelled using the measure function in ArcMap 10.3 (ESRI 2011).

We used an analytical Bayesian approach with a vague gamma prior to summarise the number of detections per perentie, as well as the number of perenties per site and per landscape. This approach produces upper and lower 95% credible intervals, which are comparable to confidence intervals produced when using a frequentist approach.

We used credible intervals because standards estimates of mean error (ie standard deviation) in count data where means are close to zero can produce nonsensical outputs, such as negative counts.

Figure B2 – An example of the spot patterning used to individually identify perentie (*V. giganteus*) within the Pilbara bioregion. The three images shown are of the same animal, and were taken over a period of 57 days (23/10/2017 – 19/12/2017) at three different camera sites. Red circles represent specific spots that were used to identify this animals.

Length measurement

We measured the snout-to-estimated vent length (SVL) of perentie individuals in camera trap images using the computer program imageJ (Abramoff *et al.* 2004). Because the vent was not visible from the dorsal surface, we consistently estimated the vent location as being at the base of the hind legs in the centre of the animal's body, based on morphometric measurement protocol used by Thompson and Withers (1997). SVL measurements followed the animal's spine from the snout to the vent to increase measurement accuracy. ImageJ allows users to measure distances within imagery by calculating a pixel-distance (mm) ratio from an object with a known length (scale) within an image. Once a pixel-distance ratio has been determined, objects with an unknown length can be measured. Here, we used brackets located at the base of tree stakes supporting cameras as the scale (40 mm). To test the accuracy of using image-j to measure animal sizes from camera trap imagery, we conducted a pilot test using Reconyx PC900 Hyperfire covert cameras and target objects with known dimensions. We found imageJ measurements varied from actual measurements (using a measuring tape) by an average of < 3%. To visualize perentie SVL data, we created histograms of SVL using *ggplot* in R version 3.5.3 (R Core Team 2020; Wickham and Wickham 2007). One SVL measurement was taken for each independent detection. When an individual was detected multiple times, and thus multiple SVL measurements were taken, we used the mean measurement.

Temporal activity

To further illustrate the range of data that can be collected for lizards using camera traps, we used time stamp data from detection images to fit non-parametric kernel density curves using the '*overlap*' package in R (Ridout and Linkie 2009), giving a probability density distribution of perentie activity patterns .This method is commonly used to quantify species temporal activity patterns within ecological studies (Allen *et al.* 2018; Azevedo *et al.* 2018; Fancourt *et al.* 2015; Lashley *et al.* 2018). We used a default smoothing parameter of 0.8 in our analysis, as recommended by Ridout and Linkie (2009) for small sample sizes.

Perenties being ectotherms, are reliant on external sources of heat to maintain a constant body temperature, which can determine when they are most likely to be active throughout the day. Because larger lizards are generally able to retain body heat longer than smaller lizards (Stevenson 1985), we expected body size to impact perentie temporal activity. To account for these differences, we analysed perentie temporal activity using three sizes classes; large (SVL >45 cm), medium (SVL = 30 to 45cm) and small (SVL < 30 cm). We determined sizes classes based on the distribution of SVL measurements collected in this study. To elucidate if perenties of different size classes were detected more frequently at different times, we measured overlap in temporal activity between large, medium, and small individuals, using an overlap coefficient (Δ). Overlap coefficients are the product of a function which describes the distance between two temporal activity density distributions, and can range from zero (no overlap) to one (complete overlap) (Ridout and Linkie 2009). We used the package *overlap*' (Meredith and Ridout 2014) in R version 3.5.3 (R Core Team 2020) to calculate temporal overlap between perentie size classes, which produces three overlap coefficients for each temporal comparison. The most appropriate coefficient for estimating overlap is dependent on sample size (Ridout and Linkie 2009). We used the overlap coefficient Δ_1 as it is most appropriate for small datasets (Ridout and Linkie 2009). Overlap precision was measured using confidence intervals generated from 500 random bootstrapped samples after accounting for bootstrap bias (Meredith and Ridout 2014).

Results

We recorded 190 detections of perentie over 28,840 trap nights. Other varanid species detected included *Varanus panoptes*, *V. pilbarensis*, *V. gouldii* and *V. acanthurus*. Perentie were detected at 91.3% of landscapes and 48.6% of sites. Seventy-three percent of detection events were suitable for individual identification, and from these, we identified a total of 92 individuals using spot pattern analysis. Confidence in identification accuracy was generally high (91%) or medium (7%). Thirty-one (33.7%) of individuals were recaptured at least once. The number of detections per individual ranged from one to five ($\bar{x}$ = 1.55, lower credible interval = 1.34, upper credible interval = 1.82), and the number of individuals detected within a single landscape ranged from zero to twenty ($\bar{x}$ = 3.99, lower = 3.22, upper = 4.86). The number of individuals per site ranged from one to 13 ($\bar{x}$ = 0.80, lower = 0.64, upper = 0.97) (Figure B3), and thirteen individuals were detected at more than one site (Figure B4,B5). The average total distance travelled between sites where the same individual was detected was 887 metres (sd = 632 m), ranging from 224 m to 1975 m (Figure B5). Average estimated SVL length was 37.22 cm (sd = 12.85 cm), ranging from 10.29 cm to 73.30 cm (Figure B6). When an individual was detected multiple times, length measurements varied by an average of 2.46cm (min = 0.64, max = 7.86), or 6.7% (min = 1.8%, max = 21.3%) of individual SVL averages (Appendix 2). SVL increased by 5cm and 7cm for two individuals that were detected 123 and 124 days respectively after they were initially detected, potentially as a result of growth. We found limited evidence of growth otherwise. Twenty-nine percent of individuals measured were classified as small (<30cm), 44% were classified as medium (30–45cm) and 29% were classified as large (>45cm).

Temporal data showed on average perentie were most active between dawn and noon, and around dusk (Figure B7). Overlap in activity patterns was highest between medium and small individuals (Δ = 0.80, lower CI = 0.63, upper CI = 0.89) and lowest between large and small individuals (Δ = 0.67, lower CI = 0.43, upper CI = 0.81). Overlap between large and medium individuals was 0.80 (lower CI = 0.55, upper CI = 0.85). Large individuals were most active between dawn and noon but also active at dusk and during the night, whereas small individuals were almost exclusively active between dawn and noon.

Discussion

Camera trap imagery is commonly used to identify individuals within mammal populations (Burton *et al.* 2015), but few have been used to individually identify lizards (Bennett and Clements 2014; Welbourne 2013). In this study, we used camera traps to identify 92 individual perenties across 23 landscapes within the Pilbara bioregion, Australia. We found a large proportion of independent detections were suitable for individual identification, and observer confidence in identification accuracy was high, suggesting camera traps may offer a practical alternative to live trapping when monitoring some large reptile species. We also highlight that other useful data, such as movement data, body length, and temporal activity patterns can be derived from the same imagery. This research highlights the significant potential of camera traps for population monitoring of large reptiles across the world.

The capacity to individually identify animals from camera trap data unlocks the use of a variety of statistical analyses that can be used to estimate population densities, as well as survival probabilities and population spatial dynamics. For example, mark-recapture models rely on individual identification to estimate abundance (Pradel 1996). We show that collecting the data necessary to perform such analyses on large lizards is possible through the use of remote sensing cameras. However, it is important to note that in addition to the ability to identify individuals, other data assumptions must be met in order to reliably estimate abundance or density using mark-recapture methods (Pradel 1996). For example, for most mark-recapture models, accuracy is highest when populations are closed (Kendall 1999); that is no deaths, births, immigration or emigration occurs across sampling periods. Whilst it is possible individuals left or entered the study population during sampling periods in our study, the likelihood of this occurring can be reduced by shortening the sampling period, or using mark-recaptures models that account for open populations (Schwarz and Arnason 1996). Low recapture rates as a result of poor capture efficiency can also impact the reliability of mark-recapture estimates (Morton 1982; Pollock 1980). In our study, we found a third of individuals were recaptured at least once, and some individuals were recaptured up to four times. This result suggests capture efficiency may be adequate for mark-recapture methods to be applied on data collected in this study, however it would be possible to increase capture efficiency by increasing the number of cameras deployed per landscape.

Perentie were detected across most study landscapes, and some individuals were detected across multiple landscapes, moving distances of almost 2km. Whilst the spatial ecology of perentie remains poorly understood, research focused on other varanids suggests movements of this distance are not unusual (Green and King 1978; Guarino 2002). We also found a number of individuals were recorded visiting the same camera sites repeatedly (up to five times), sometimes over a period of months. Whilst we may only speculate where these individuals travelled in the time between detections, habitual visits to the same site could indicate some individuals may occupy a home range like other varanids (Lei and Booth 2018).

One disadvantage associated with using non-capture related techniques to survey wildlife is the lack of ability to collect morphological data. In this study, we were able to approximate perentie SVL by scaling images to a known distance. SVL length varied substantially between individuals suggesting camera traps were able to detect a range of demographics ranging from juveniles (SVL = 10.3 cm) to larger adults (SVL = 73.3 cm). Average SVL length was 37.22 cm (min = 10.3cm, max = 73.3 cm), which fits within the bounds of previous measurements that were recorded in situ on perentie in Western Australia. For example Thompson and Withers (1997) found average SVL length from 25 captured perentie was 44.2 cm (sd = 12.4 cm), ranging from 15.9 cm – 66 cm. Similarly King *et al.* (1989) found SVL length of captured perentie on Barrow Island ranged from 23 cm – 88 cm (no average available). Whilst estimating body length using scaled imagery is an accepted method within wildlife research (Weinstein 2018), in our study, uneven ground surfaces on top of which lizards were measured has the potential to distort estimates. Despite this, we found measurement consistency was relatively high (average variation from mean individual SVL = 6.7%). This result suggests that, although SVL measurements using camera trap imagery are obviously less accurate than measurements obtained with animals in hand, they may be able to provide reasonable estimates of animal size that could potentially be used to infer other individual attributes such as age and sex (although see Smith *et al.* 2007). A practical means of improving length estimates using camera traps in future studies may be to install a flat base plate underneath cameras (following Welbourne 2013; Welbourne *et al.* 2015), so that variation in the surface on which animals are measured is removed.

Behavioural data can be important to species conservation (French *et al.* 2019; Tyne *et al.* 2017), yet accessing this data usually involves tracking an animal using expensive satellite telemetry equipment (Bastille-Rousseau *et al.* 2018; Hertel *et al.* 2019), or investing large quantities of time manually recording animal activity in the field (Brieger *et al.* 2017; Li *et al.* 2017). We used time stamp data imprinted on camera trap imagery to record perentie diel activity. Temporal activity varied between perentie size classes, however overlap between perentie size class combinations was mostly similar (Δ0.67–Δ0.80). The most notable differences in temporal activity were observed in temporal activity peaks. For example, activity peaks for large and medium sized individuals were spread across much of the 24-hour diel period, occurring at mid-morning, dusk and midnight, whereas activity for small individuals was mostly confined to mid-morning and early afternoon. Observed temporal differences could be related to individual physiology, where individuals with larger body mass are able to thermoregulate more efficiently than individuals with smaller body mass, and thus stay active longer (Garrick 2008). Alternatively, smaller individuals may avoid being active around dusk and at night to reduce their likelihood of encountering potential predators such as feral cats (*Felix catus*) and dingoes (*Canis dingo*) which are generally most active at these times within the study area (GéCzy 2009; Hernandez-Santin *et al.* 2016; Johnson 1976). Whilst some varanids are known to predate on smaller members of their own species (Polis and Myers 1985), our results do not suggest smaller perenties are temporally avoiding larger perenties. This is because peak activity of large and small perenties overlaps considerably around 11:00am. Further, smaller perenties are not active at any time larger perenties are not active.

Another explanation is that cameras fail to detect smaller lizards at night due to a lack of thermal contrast. This is consistent with the findings of Richardson *et al.* (2018), who found that camera traps failed to detect small, nocturnal reptiles. Passive infrared triggered cameras, as used in this experiment, will detect an animal when a difference between the animals surface temperature and the background temperature is detected, (Welbourne *et al.* 2016), with optimal conditions for detection occurring when the temperature difference is at least 2.7° C (Meek *et al.* 2012). When the background temperature is similar to an animals surface temperature, the capacity of PIR cameras to detect the animal may be reduced (Rovero *et al.* 2013). On the basis of these facts and the laws of thermodynamics, the surface temperature of smaller perentie individuals maybe more similar to the background temperature — derived from the red granite on top of which cameras were positioned — because they have a smaller body mass, and therefore maybe less likely to be detected by PIR sensors. Contrast between the background temperature and surface temperature of smaller perenties may be larger in the day because animals are better able to thermoregulate by utilizing microhabitats that are cooler than the rest of their environment (Sears *et al.* 2016). To increase thermal contrast when using PIR cameras to detect lizards Welbourne (2013) successfully augmented background temperature using cork tiles, making the lizards more visible to sensors. Whilst implementing a similar technique would have been desirable in this study, unfortunately it was logistically not possible.

Recent improvements in remote sensing technologies have created opportunities for wildlife research to utilize non-invasive labour efficient techniques instead of methods that involve the live trapping of animals. Importantly, we recognise that although many large species of lizards bare natural markings that could potentially be used to tell animals apart (Chen *et al.* 2013; King and Horner 1987; Rodda *et al.* 1988), consistent individual identification may not be feasible for all species, especially those which lack spot or line based scale patterning. One potential objective of future research could be to explore the practicality of using camera traps to individually identify animals from other lizard taxa that exhibit visible scale patterning, such as species with the Agamidae and Scincidae families (Welbourne 2013). Another objective could be to trial alternative camera types and settings that may be better suited to detecting smaller species, whilst still providing high resolution imagery. Preliminary research in this area suggests cameras programmed to take images at standard intervals capture more images of squamates than cameras triggered by sensors, and cameras with a manually adjusted focus collect images better suited to identifying smaller lizards than cameras which use default focus settings (Welbourne *et al.* 2019). In this study, we demonstrate how camera traps can be used to detect Australia's largest species of lizard and provide imagery that can be used to differentiate individuals as well as observe temporal behaviour. Overall the findings of our study provide a promising indication of the potential uses for camera traps in studying large lizards and herpetological research in general.

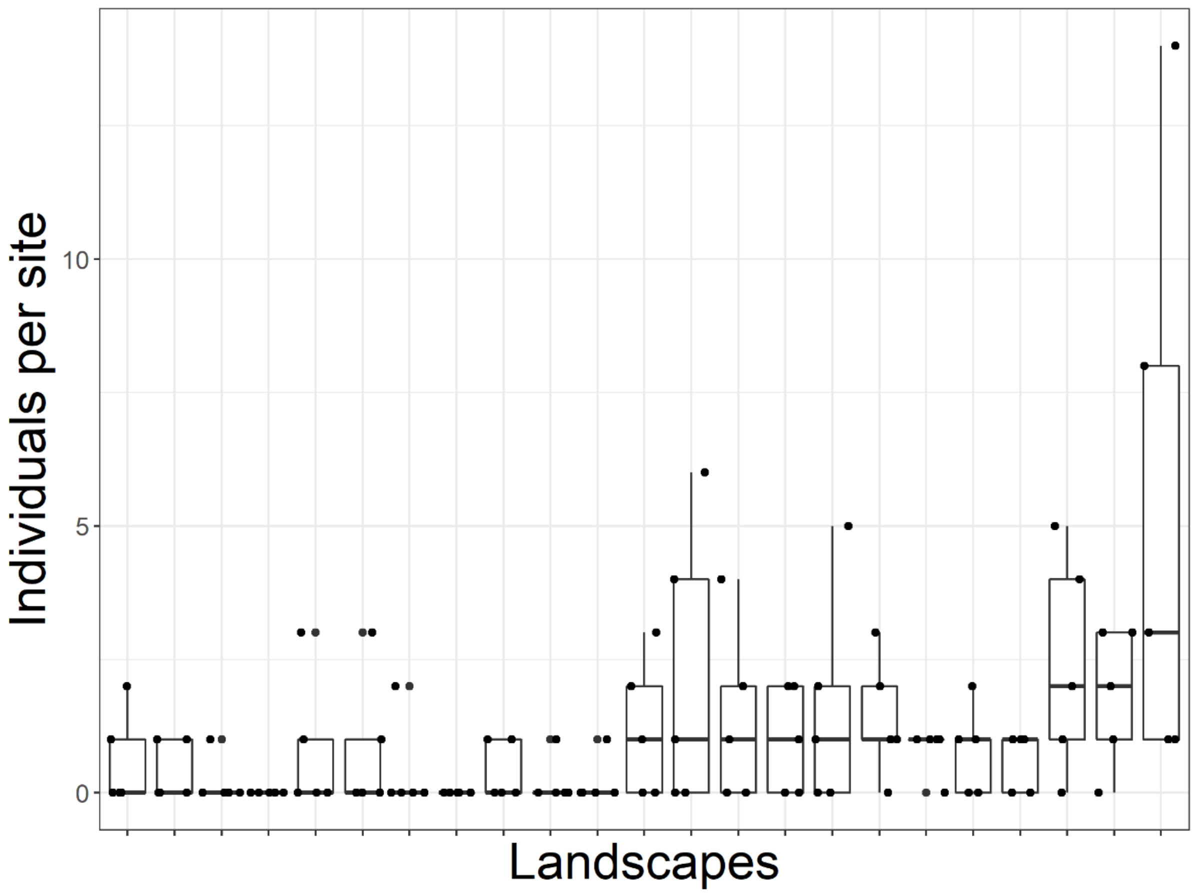

Figure B3 – Boxplots depicting the total number of perentie (*Varanus giganteus*) individuals detected at study sites grouped within the 23 study landscapes within the Pilbara bioregion in Western Australia. Five study sites were within each study landscape.

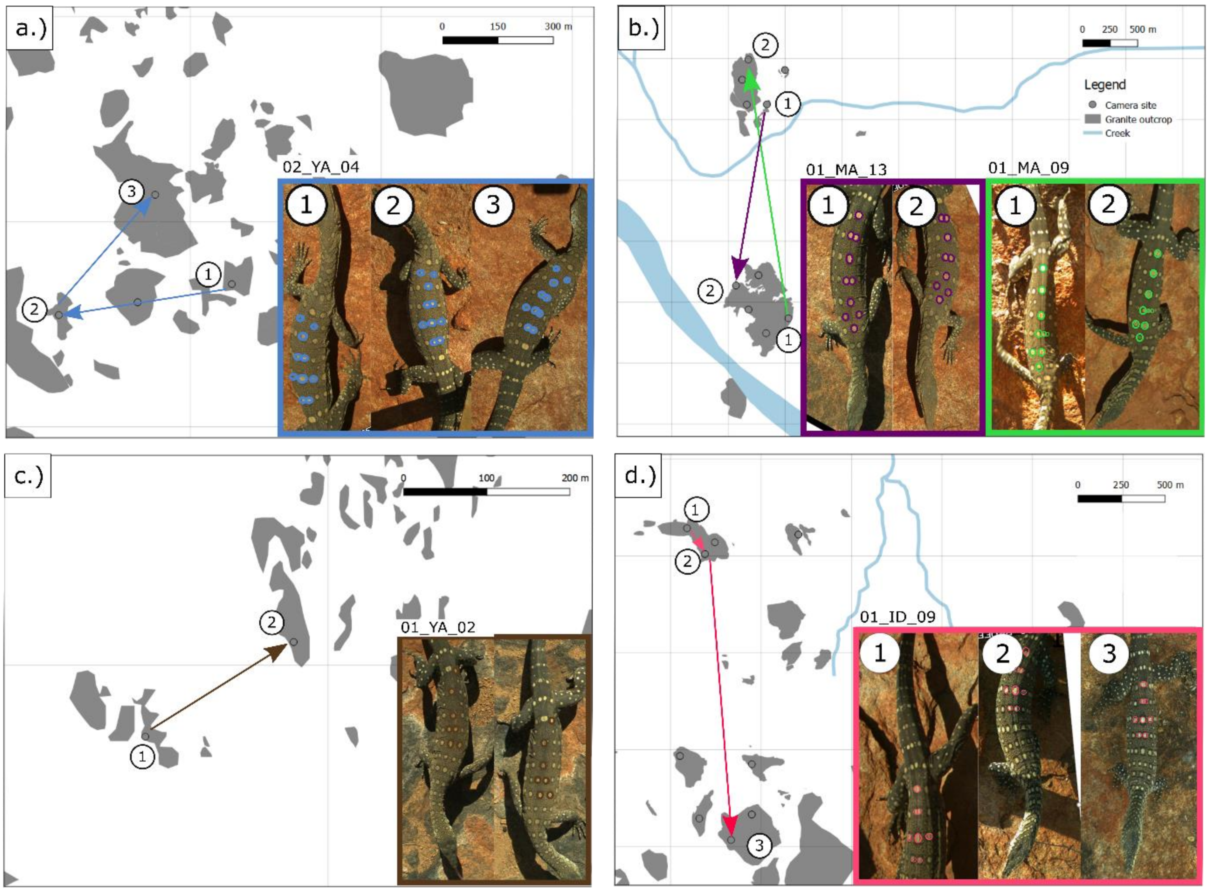

Figure B4 – Perentie (*Varanus giganteus*) individuals detected at multiple study sites within the Pilbara bioregion in Western Australia. a.) Individual 02_YA_04 was detected at site Q0704 on 30/09/2018 before moving 508 metres to site Q0701 on 30/10/2018 and then 431 metres to site Q0703 on 05/01/2019. b.) Individual 01_MA_13 was detected at site Q6603 on 25/09/2017 before moving 1573 metres to site Q3205 on the 8/11/2017. Individual 01_MA_09 was detected at site Q3202 on 15/01/2018 before moving 1975 metres to site Q6601 on 10/03/2018. c.) Individual 02_YA_04 was detected at site Q0704 on 30/09/2018 before moving 508 metres to site Q0701 on 30/10/2018 and then 431 metres to site Q0703 on 05/01/2019. d.) Individual 01_ID_09 was detected at site Q2201 on 23/10/2017 before being detected 201 metres away at site Q2202 on 24/10/2017 and then 1245 metres away at site Q1905 on 19/12/2017.

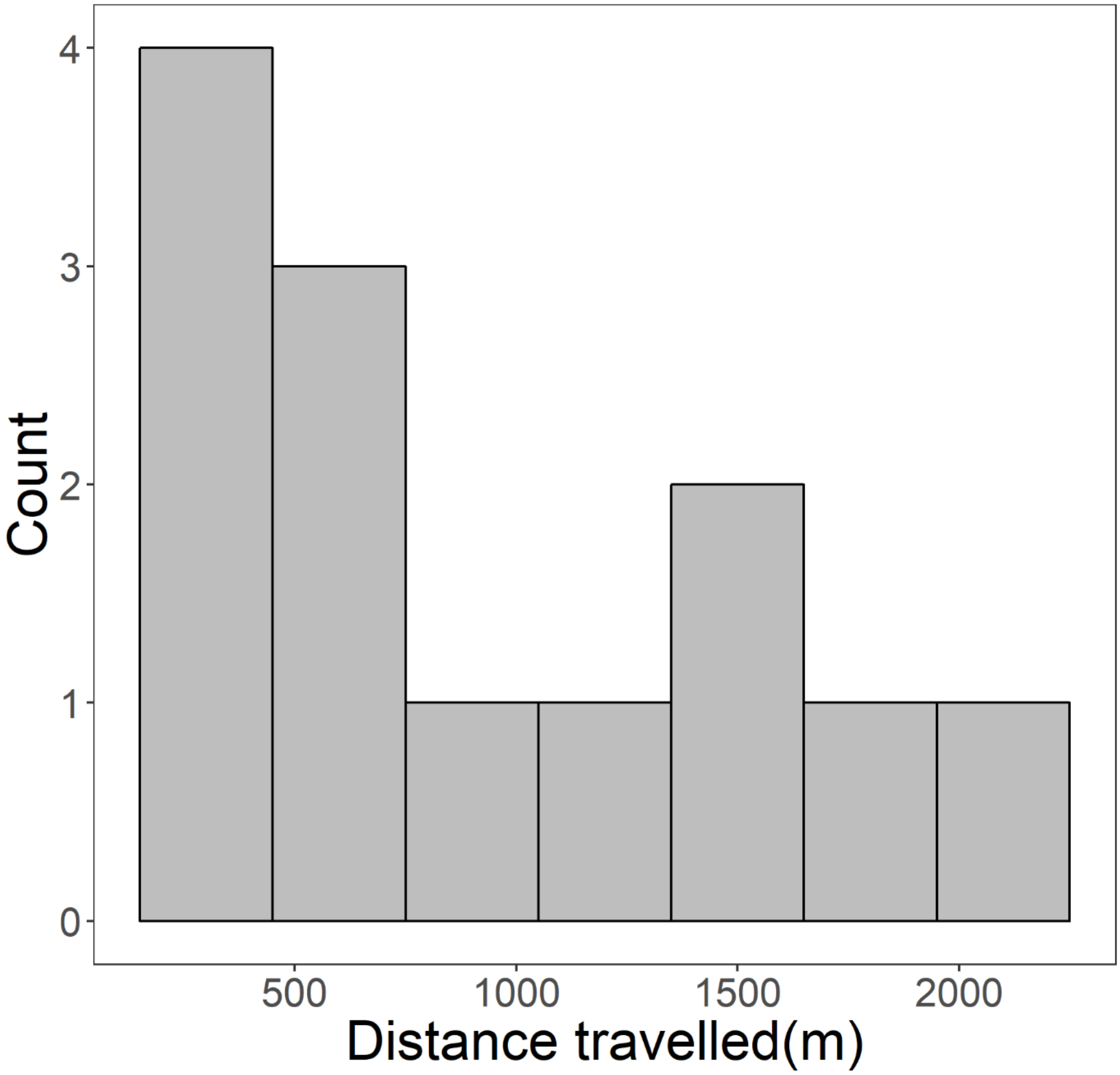

Figure B5 – Histogram depicting total distances travelled (m) by the 13 Perentie (*V..giganteus*) individuals that were detected at more than one study landscape within the Pilbara bioregion .

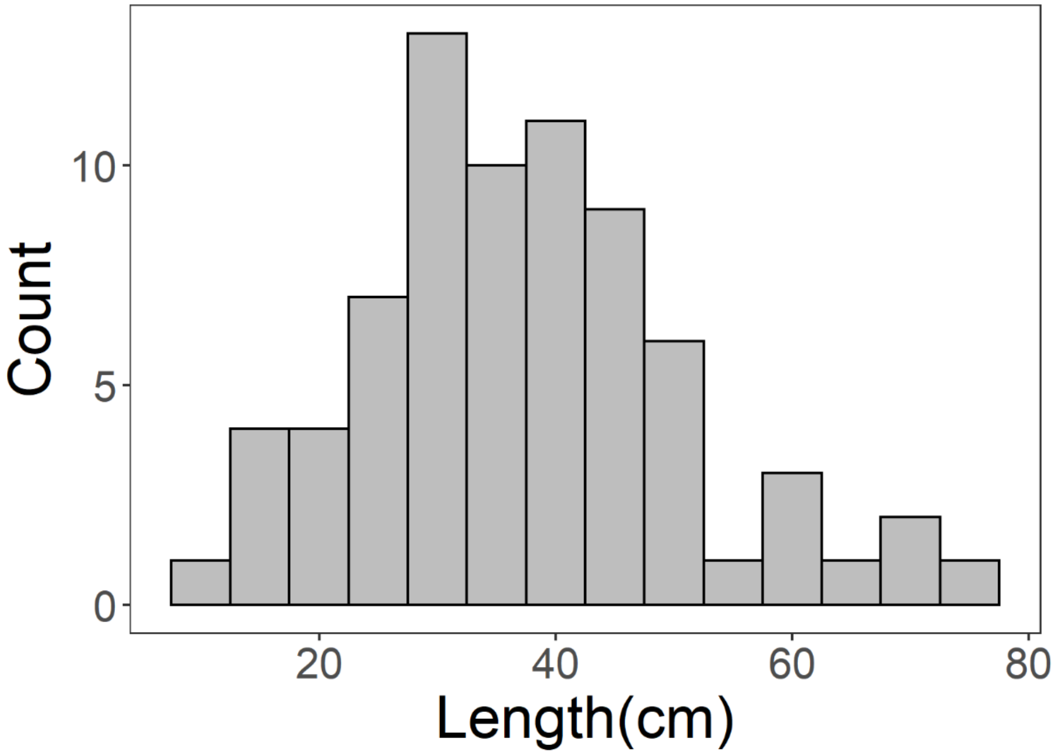

Figure B6 – Histogram depicting the averaged snout to estimated vent length (cm) of 73 Perentie (*V. giganteus*) individuals that were measured from camera trap image using freely available image analysis software.

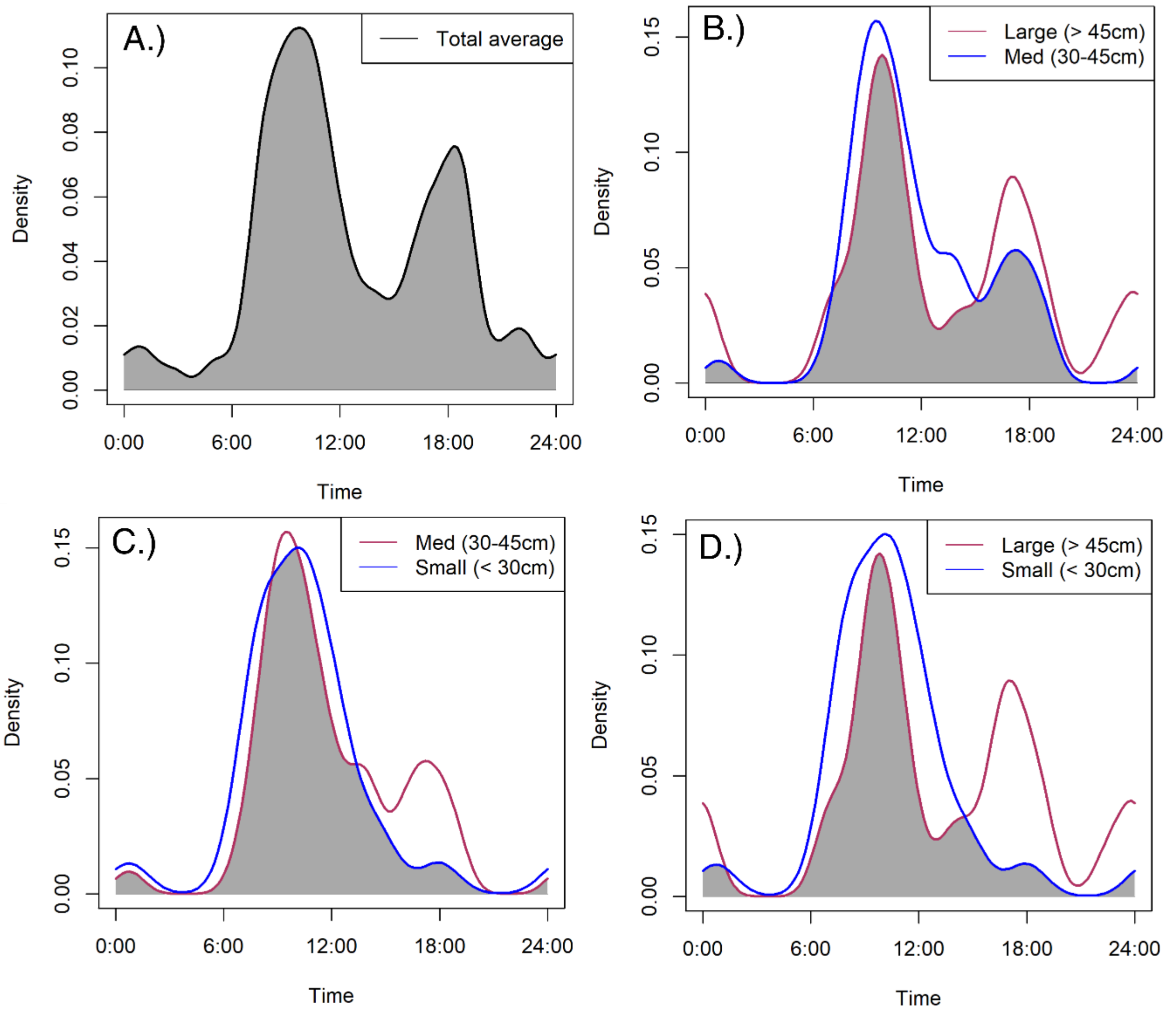

Figure B7 – Non-parametric kernel density curves depicting temporal activity for Perentie (*Varanus giganteus*) in the Pilbara bioregion recorded using camera traps. Grey sections represent overlap in temporal activity. Large individuals were individuals with an average SVL exceeding 45cm. Medium individuals were individuals with an average SVL between 30 cm and 45 cm. Small individuals were individuals with an average SVL less than 30cm. A.) Averaged temporal activity for all individuals B.) Overlap in temporal activity for large and medium individuals C.) Overlap in temporal activity for medium and small individuals D.) Overlap in temporal activity for large and small individuals.

Appendices

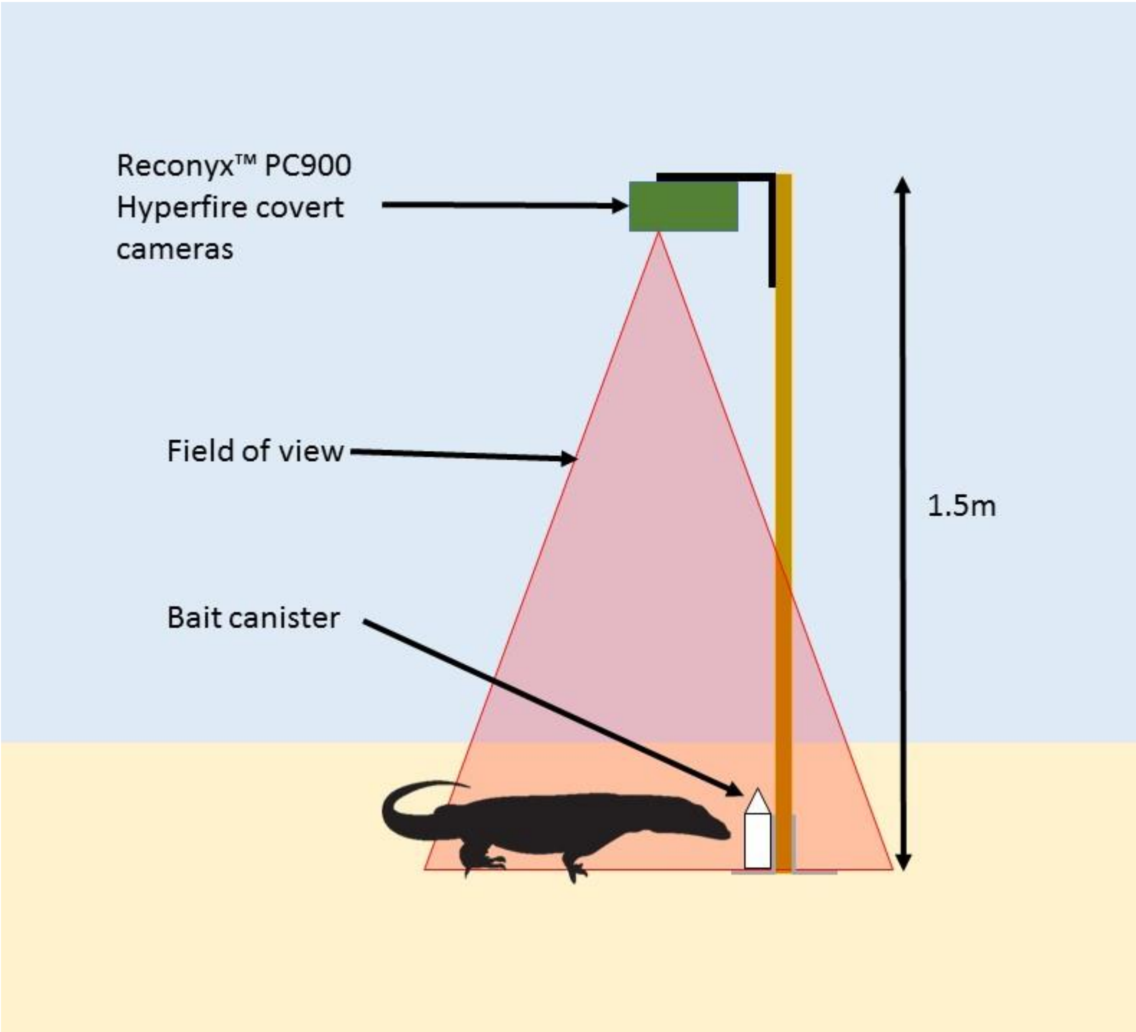

Figure BS1– Schematic of camera trap design used to detect and identify Perentie (*V. giganteus*) individuals.

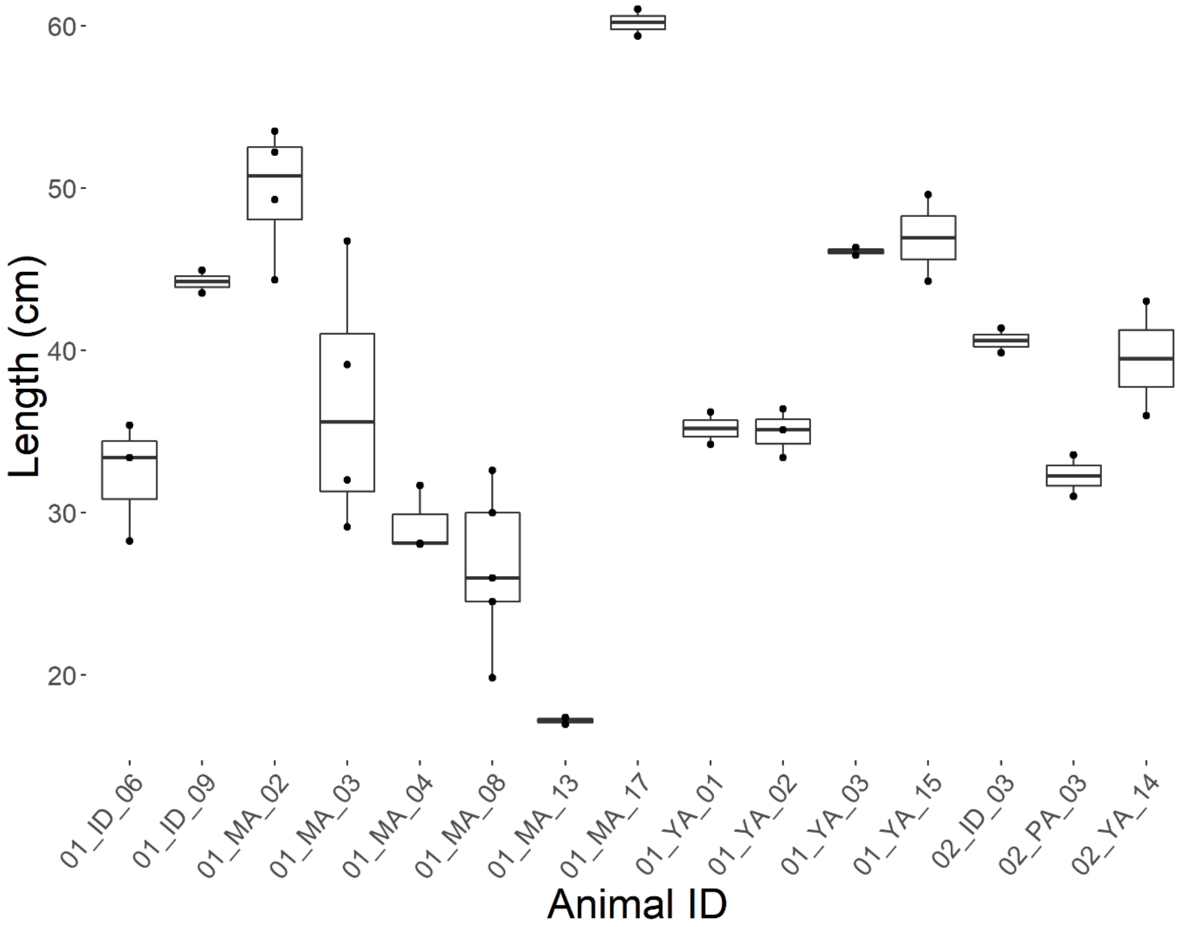

Figure BS2 – Boxplot depicting variation in the snout to estimated vent length (cm) of 15 Perentie (*V. giganteus*) individuals that were measured from camera trap image using freely available image analysis software

Acknowledgements

Data collection was assisted by Sian Thorn, Darcy Watchorn, Rainer Chan, Daniel Bohorquez Fandino, Jacob Champney, Hannah Kilian, Mitch Cowan. Camera trap deployment was also completed with the assistance of the Yandeyarra Indigenous ranger program facilitated by Pip Short and Greening Australia. Technical support was provided by Neal Birch, Brent Johnson, Hannah Anderson, Russell Palmer, Alicia Whittington and Jo Kuiper from the Western Australian Department of Biodiversity, Conservation and Attractions (DBCA), as well as Deb Noy from Charles Sturt University. Stephen Van Leeuwen from DBCA provided assistance with the project conception and also provided support throughout. Equipment and operational costs were provided by DBCA, Roy Hill and Charles Sturt University. Roy Hill also covered the costs of flights, fuel and freight. Harriet Davie from Roy Hill provided technical support throughout along with the Roy Hill rail team in Port Hedland. We thank Colin Brierly, Betty Brierly and Graham for providing access to Indee station, Ben and Lindsey for access to Mallina and Troy Eaton for access to Pippingarra. Belinda Barnett from BHP assisted with site access. H.A.M is supported by a scholarship from the Institute of Land, Water and Society and Charles Sturt University. L.E.V. was funded by the Australian Government's National Environmental Science Program through the Threatened Species Recovery Hub. D.G.N. was supported by an Australian Research Council Early Career Researcher Award (DECRA). This project was supported by the Holsworth Wildlife Research Endowment – Equity Trustees Charitable Foundation & the Ecological Society of Australia, as well as the Western Australian Department of Biodiversity, Conservation and Attractions as well as environmental offsets and public good funding provided by BHP, Rio Tinto, Atlas Iron, Fortescue Metals Group, Roy Hill, Process Minerals International, Metals X and Main Roads Western Australia. Research ethics was granted though the Charles Sturt University animal ethics committee (permit number A17031), and the Western Australian Department of Biodiversity, Conservation and Attractions (permit number 08-002376-1).

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