The impact of climate change on the reproductive demography of the banded mongoose (*Mungos mungos*)

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Abstract

Anthropomorphic activities such as burning of fossil fuels are causing an accelerated form of climate change which is increasing global temperature, altering rainfall patterns, and increasing rates of climatic instability. In tropical regions, temperatures are rising, and rainfall is becoming less predictable, with increases in flooding and droughts. However, we know little about the impacts of changes in temperature and rainfall on the demography of wild animals, particularly communally breeding species. Banded mongooses provide a good opportunity to understand climate change impacts as their prey abundance decreases when there is less rainfall, impacting the foraging behaviours of the species. However, there is little knowledge on the direct impacts of climate change on the reproductive demography of the species. Here I use reproductive data collected from a long-term field project on banded mongooses in Uganda, where there are two rainy seasons per year with relatively dry periods in between. I find that there is variation between rainy seasons in the amount of rainfall that occurs, but being equatorial, there is little seasonal change in temperature. I find that reproduction in banded mongooses follows seasonal changes, with breeding peaking during rainy seasons and at lower temperatures. Over the 19-year study period, the number of females giving birth and the number of pups produced are highest in rainy seasons with high rainfall but tend to decrease in rainy seasons with elevated temperature. My results demonstrate that reproduction in banded mongooses is likely responding to climate change, and with the risk of future temperatures rising further, the number of pups born into the population may decrease over time. Understanding exactly how climate change affects a population allows for better monitoring in seasons when climate conditions are predicted to be worse.

Lay summary

Banded mongooses are small mammals that are found across sub-Saharan Africa, Botswana, and the Serengeti. They prefer living in woodlands, grasslands, and savannahs, where more insects are found to feed upon. Banded mongooses live in social groups of approximately 10 - 40 individuals consisting of males, females, and pups. The pups are born at the same time in underground dens where they remain for a total of 30 days until they are old enough to leave the dens. Once independent the pups are taught by adults how to find food and protect themselves. Previous studies of this species found that rainfall impacts their food sources as when it is high more insects are present to feed on. But during rain storms mongooses will not leave the den to find food as they do not like being out in the rain. However, not much is known about the possible direct effects of climate change on the reproductive demography of the banded mongooses. To understand the impacts of climate change I investigated (1) the impact of seasonal changes in rainfall and temperature on the birth rate and number of pups born into the population and (2) if variation between rainy seasons (e.g., droughts) affected breeding parameters. The data used in this investigation was obtained from the Banded Mongoose Research Project in Uganda, which has been collecting data on this species for over 20 years. In total, over 3,000 individuals were monitored between 2000 and 2019, with data being collected from 38 rainy seasons (some of which had higher levels of rainfall than others). I found that over the course of a year, banded mongooses concentrated their reproduction into the two rainy seasons. I also identified that over the 38 rainy seasons included in this study, changes in climate do have an impact on the number of breeding females the number of pups born, pup survival and ratio of females born. Specifically, more pups were born in rainy seasons with high rainfall and lower temperatures. Overall, I can say that climate change is likely to have an impact on reproduction in banded mongoose populations, and that this knowledge will hopefully help to create new conservation tactics in order to help protect banded mongooses from future climate events. It also highlights that a species previous thought unaffected may be impacted as a result of climate change.

University Declarations and Statements

I declare that the work carried out in this thesis has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

I declare that this thesis is the result of my own investigations, except where otherwise stated and that other sources are acknowledged.

I consent for this thesis, if accepted to be made available online in the University's Open Access Repository and for inter-library loan, and for the title and summary to be made available to outside organisations.

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Statement of contributions

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Covid-19 statement

During the COVID-19 pandemic my mental wellbeing had been effected and took a toll on the creation of this thesis from formatting onwards. As a result, I feel that it has affected my study much more than what it originally would have been under normal working conditions. Additionally, the communication between myself and the researchers was slow as several emails had to be sent back and forth to help correctly format the data. In total, formatting took several months to complete as each new reproductive parameter used in this study was made of several different variables. I also had no first-hand experience with the population itself, comprehending how the population interacted on a daily basis was a struggle when forming an analysis from my results. COVID-19 stopped a planned trip to the field site where I would have monitored the population first-hand which would have helped me build context to my early results.

Ethics Approval

This thesis has been approved under Swansea University ethics guidelines.

Reference number: STU_BIOL_132237_040220173112_1

Approval number: SU-Ethics-Student-040220/2515

Health and safety and Risk Assessment

A risk assessment for this thesis was carried out prior to this study, the full form was submitted and emailed to Dr Christopher Coates.

Contents page

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I would like to thank my supervisor Dr. Hazel Nichols as over the course of this study Hazel has helped me make this thesis possible, especially during the Covid-19 pandemic where life was uncertain from time to time. She has helped me through thick and thin and I would just like to say thank you for everything you have done for me. Whether it was about the project, helping me figure out what I want to do next or helping me support myself and my mental wellbeing during lockdown.

I would also like to say thank you to the researchers dedicated to recording and monitoring the banded mongoose population in Uganda and for allowing me to use the data they collected for this thesis.

And finally, I would like to thank my family and friends that were there for me during my masters, whether it was keeping me sane in lockdown (Lewis, Liv and Catrin) with daily activities or helping me proofread when my eyes couldn't take it anymore (Jo and mum). I don't think I could have done it without the support and encouragement that you all gave me so thank you.

Illustration and table list

Figures

Tables

Definitions and abbreviations

(BMRP) - Banded Mongoose Research Project

(GLMs) - Generalised Linear Models

(IPPC) - The International Panel on Climate Change

1. Introduction

The climate is the pattern of weather across an area over extended time periods, typically decades, incorporating such variables as temperature and rainfall (Solomon et al., 2009). While the Earth's climate is not static and has alternated over millennia, an accelerated form of climate change has developed due to increasing anthropogenic influences (O'Brien et al., 2006). Excessive release of carbon dioxide (CO_2) from the combustion of fossil fuels and the inability to sequester the majority of the greenhouse gas due to rapid rates of deforestation, are the largest contributors to the acceleration process (Ghommem et al., 2012). Global temperature has shown to continually increase since the 1880's with a total rise of approximately 1.2°C (World of Change: Global Temperatures, 2020, Figure 1). Future projections indicate that if no intervention is actioned global temperatures are set to potentially increase by a further 3°C (Grafßl et al., 2003). A likely result of this prediction is that global conditions will continue to heat and place stressors on regions as they are unable to cope with the rapid rate of change and render regions of the globe or habitats damaged to a much greater extent (Visser, M.E., 2008).

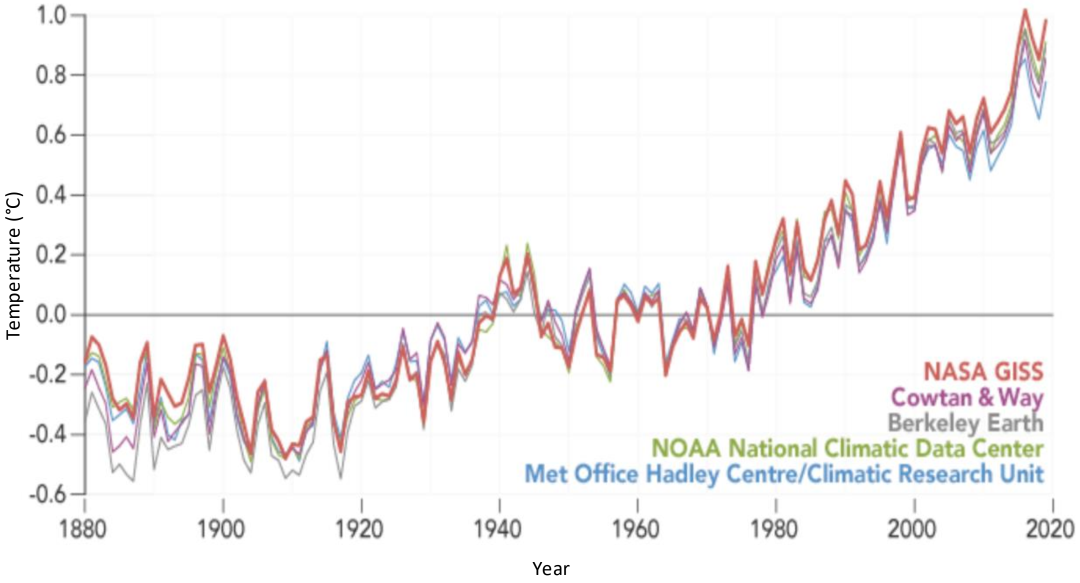

Figure 1: Yearly temperature anomalies from 1880 to 2020 from five independent sources listed above, showing the rate of changing global temperature (World of Change: Global Temperatures, 2020).

Over the past century, extreme weather events (storms, droughts, and heatwaves) have increased in frequency and severity, this trend is expected to continue (Ackerly et al., 2010; Westerling and Bryant, 2008). Cooler regions like Northern Russia have recorded soil temperatures rising by approximately 0.31°C per decade over the last 40 years as a result of climate change which has therefore increased the rate of snow and ice melt (Chen et al., 2021). Similarly, regions that are noticeably warmer in temperature like sub-Saharan Africa are also beginning to warm, with associated reduced rainfall and increased the strength of droughts (Gautam, 2006). A recent drought in Australia lead to a widespread series of bushfires in 2019/20 due to the hotter than average summer (hottest day: 42.4°C), causing vegetation to dry out and catch on fire (Clark, 2020). A total of 5.3 million hectares of land was destroyed, including national parks and wild areas across the country, resulting in the loss of approximately 1.25 billion animal lives (Sydney in Summer 2019, 2021). If temperatures within Australia remain at the current level, the frequency and intensity of bushfires are likely to increase. Recovery time for these ecosystems will shorten which can potentially increase rates of extinction (Urban, 2015). Extreme weather caused by climate change will produce lasting effects on ecosystems and potentially on the recovery and survival of species at exposed to these events.

Large-scale events associated with changes in climate are generally easy to identify, for example when there is widespread mortality. However, not all effects are noticeable, specifically on an individual level. Shifts in phenology, population distribution and demography have been recorded within both animal and plant species as a result of climate change (Moritz et al., 2008; Ackerly et al., 2010). For example, over the last three decades, birth weights of Antarctic fur seals (*Arctocephalus gazelle*) have been declining, leading to high mortality levels and low recruitment into the population (Forcada and Hoffmann, 2014). These low survival rates appear to be due to smaller females having low survival when their krill food source is in short supply when waters are warm (Forcada and Hoffmann, 2014). Similarly, in African Wild dogs (*Lycan pictus)*, increased ambient temperatures have been recorded to negatively impact their reproductive success: packs found in hotter areas are producing fewer pups compared to packs in cooler regions, resulting in fewer recruitments into these specific adult populations (Woodroffeet et al., 2017).

It has been proposed that cooperatively breeding species are to some extent buffered against climatic changes in their surrounding environment. Protection is afforded against environmental variation by the breeding system as they breed cooperatively with mature group members caring for multiple pups at any one-time. Larger social groups with more adult helpers have shown to buffer temperature influence, with pups in smaller groups having reduced growth rates under high environmental temperatures (Van de Ven et al., 2020). However, buffering has not been found in all cooperatively breeding species. For example, pied babbler (*Turdoides bicolor*) helpers are unable to buffer against the impacts of droughts as the hot and dry conditions cause reduced juvenile growth and cause mass loss in adults, regardless of group size (Bourne et al., 2020). This lack of adjustment from the piped babblers does indicate that there is variation between species when it comes to the potential ramifications of climate change. Identifying differences are vital to understanding the extent to which different species are able to successfully protect themselves from climatic changes.

The majority of studies carried out on the impacts of climate change on cooperative breeding species have focused on species that are commonly found living in arid regions, while there is little literature showing how species living in equatorial regions are being influenced. The average climate of equatorial regions consists of relatively high but stable daily temperatures and a higher level of rainfall than arid environments. Data has shown that Uganda (an equatorial country) is facing greater rates of warming than in previous years; between 1900 and 2009 the regional temperature has increased by 1.5°C and there has been a decline in rainfall by approximately 8% (Funk et al., 2012). Currently little is known about how this is impacting wild populations as most studies focus on the impact on arable farmland. As it stands, vegetation is slowly receding as less land has suitable conditions for plant growth (Funk et al., 2012, Kizza et al., 2017). A population of banded mongooses (*Mungos mungos*) found in Queen Elizabeth National Park, Uganda, has been studied for the past 20 years, providing an opportunity to investigate the potential impact of climate change over an extended period of time on a cooperatively breeding species in an equatorial region.

Banded mongooses are small (<2kg) insectivorous mammals that live within social groups of approximately 10 – 40 individuals (Gilchrist, 2004; Nichols, Jordan, Jamie, et al., 2012). They are cooperative breeders that are distributed across Eastern, Central and Western Africa (Cant et al., 2013; Hodge, 2005). Their main sources of food consist of various invertebrate species, small reptiles, small mammals, and fruits that are found within their habitat, which are woodlands, grasslands, and savannahs (Gilchrist and Otali, 2002). The aforementioned decrease in rainfall in Uganda is likely directly effecting the invertebrates that the population feeds upon as invertebrate populations have been shown to decline after periods with no rainfall (Marshall et al., 2017). However, studies have not fully investigated the direct impacts of long-term rainfall and temperature changes on the general breeding demography of banded mongooses. Nichols et al., (2012), found that the lack of rainfall in months previous to birthing events reduced the likelihood of females giving birth and negatively impacted on the weight of pups produced. Birth rate in banded mongooses is also more understood as females are likely to abort pregnancies when the benefit of losing the litter outweighs the cost of completing it (Inzani et al., 2019). However, this does not show effects from the season in which these reproductive events take place in.

The aim of this study is to investigate the potential impacts of climate change on the reproductive demography of banded mongooses. This will be achieved by looking into the patterns of temperature and rainfall over a 19-year period to understand (1) if there are any seasonal patterns of reproduction over an average year that relate to changes in rainfall and temperature (2) how reproductive parameters relate to long term changes in climate. In total five aspects of the breeding demography were investigated within this study; the number of females that carried a litter to term, the number of pups produced, the rate of pup survival to 90 days, the rate of litter emergence from the den (at 30 days), and the sex ratio (percentage of females) of litters born. I will also investigate whether temperature and rainfall interactions (i.e., droughts) have any influence over the population. From previous studies such as Marshall et al., (2017), I predict that rainfall has the potential to have a greater influence on banded mongoose reproduction than temperature, as prey levels have already been shown to respond to rainfall.

2. Methods

2.1 Study system

All data used in this study was collected as part of the Banded Mongoose Research Project (BMRP) that has run continuously since 1995 on the Mweya Peninsula, found within the Queen Elizabeth National Park, Uganda (Marshall et al., 2018, Figure 2b). The site is populated by 10 – 12 social groups over a range of 5 km^2. Each group is located by fitting one or two individuals within each group with a radio collar (Cant et al., 2013; Marshall et al., 2018). Each group is monitored every 1-3 days for a minimum of 20 minutes to collect behavioural and demographic data (see below, part 2.4 for details) (Marshall et al., 2018). In total, data has been recorded on 3,056 individuals between 2000 and 2019.

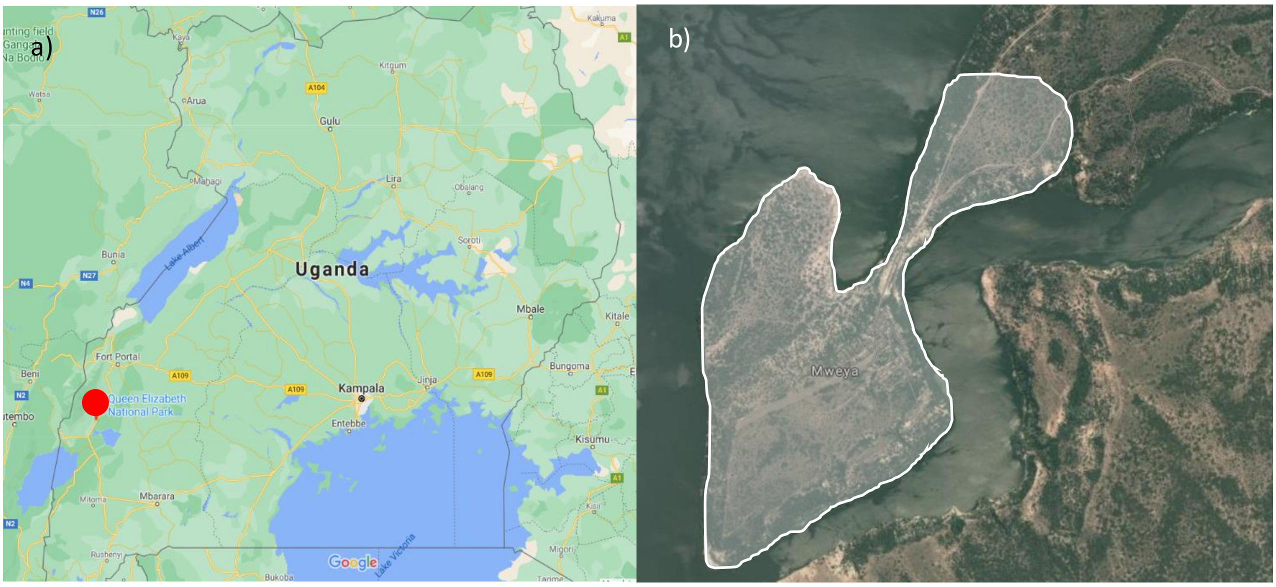

Figure 2: a) Map of Uganda with the study site highlighted by a red pin in the southwestern region of the country, b) satellite map of the Mweya peninsula with the banded mongoose study site highlighted in white. (extracted and modified from google maps)

2.2 Study species

The reproductive skew of banded mongooses is low as multiple females breed together during a reproductive event (Gilchrist et al., 2004). However, when resources are in short supply, older and more dominant females forcefully evict younger cohorts of females from the group, causing the evictees to either abort their pregnancy before returning or leave to form a new social group (Cant et al., 2010; Nichols et al., 2012). Females within social groups synchronise oestrus within a day or two of each other leading to a coordinated breeding event (Rood, 1975). Synchronised breeding increases individual reproductive success as it reduces the risk of infanticide from other females when pups are born early and competition from older littermates if pups are born late (Hodge et al., 2011). Gestation in females lasts approximately eight weeks and per year there are at least two breeding events per social group, but there can be up to four (Cant, 2000). In each breeding event, pups are born in an underground den where they are communally cared for by both males and females (some of which are non-breeding helpers) until pups emerge from the den at approximately 30 days old (Rood, 1975). After emergence, each juvenile is cared for by a single adult in a 1:1 relationship until the age of three months (90 days old) (Vitikainen et al., 2019).

2.3 Meteorological data collection

Meteorological data has been collected daily for a total of 21 years from 1999-2020. Three climatic variables; rainfall, maximum temperature, and minimum temperature, were recorded via a local weather station located within the study site on the Mweya peninsula (Marshall et al., 2017). From the original climate dataset, some years were excluded, as the years had incomplete data records; 1999 (data was missing between January and March), 2002 (which only had records for January and half of February), and 2020 as data was being collected concurrently with this study was also excluded. Therefore, this study is based on 19 years of meteorological data and the corresponding biological data.

2.4 Demographic data collection

During the observation period from 1999 to 2019, multiple behavioural, demographic and life history events were recorded to form a comprehensive database of the banded mongoose population at the study site. At first emergence from the den (30 days old), each pup is taken by lightly picking them up by the scruff to give them physical identifying marks such as haircuts or a small patch of hair dye (Cant, 2000; Nichols, et al., 2012). Adults were given the same markings but were trapped in baited cages and were anaesthetised beforehand. For full trapping details see Cant et al., (2002). Some adults were also fitted with colour coded plastic collars to allow for fast identification, making it easier to find key individuals in the field (Jordan et al., 2010). Markings and collars were routinely renewed by re-trapping marked individuals every 3 – 6 months (Hodge, 2007). During trapping events, sex is established by examining the genital region of the individual, however some pups die before sex is determined so not all pups are identified with a sex.

Alongside the physical trapping of individuals, visual observations were recorded during the daily visits to the study site. Females were identified as pregnant by observing the shape of their abdomens, and if it was distended then they were classed as pregnant (Gilchrist, 2006). A female was recorded as having given birth when her abdomen was no longer distended. This visual cue also acted as an indicator of females who had aborted their pregnancies in the later stages of pregnancy (Gilchrist, 2006). Once females had given birth, the pups remained inside the den for approximately 30 days and after this period pups emerged and began accompanying their social group on foraging trips. If no pups emerged from the den, this indicated that the litter had not survived.

2.5 Data analysis

All Generalised Linear Models (GLMs) were constructed using base RStudio 4.0.2 (R Core Team, 2020). First, I investigated patterns of breeding across the year to identify seasonal changes in reproduction that are associated with changes in temperature and rainfall. Here each data point for the explanatory variables was a total for each month across all years (i.e., a total for all January's, all February's etc). The response variables were 1) the number of females giving birth and 2) the number of pups produced (Table 1) and the explanatory variables were 1) mean monthly rainfall, 2) the proportion of days with rainfall, 3) mean maximum temperature, and 4) mean minimum temperature (Table 2). The explanatory variables were tested in separate models to avoid overparameterisation due to the smaller data set (12 data points). In total, eight models were run for this analysis.

Second, I evaluated the effect of climatic conditions across 38 6-month rainy periods, that from this point on will be termed ‘rainy seasons’, occurring between 1999 and 2019. For this investigation I split each year into two corresponding sections (Season A: January – June, Season B: July – December). Five reproductive parameters were analysed, 1) the number of females giving birth, 2) the number of pups produced, 3) pup survival, 4) litter emergence, and 5) the sex ratio of pups produced (Table 1). The explanatory variables remained the same as the previous set of models. As the data set for these models were larger, the risk of overparameterisation was low, so multiple climatic variables could be tested in each model. In total 10 modes were run for this section of the investigation. Finally, in order to investigate if there was any effect from drought conditions (low rainfall combined with high temperatures), each reproductive parameter (table 1) was tested to identify any interaction between the reproduction and droughts. These models had the same larger data set so multiple explanatory variables could be tested at the same time. Five models were run in total.

Table 1: Description of reproductive parameters used within this study.

Reproductive parameter	Description	Model type
Number of females giving birth	A count of the number of females across the study population that had given birth within the relevant time period.	GLM - Poisson
Number of pups produced	The number of pups produced within the study population over the relevant time period.	GLM - Poisson
Survival of pups	The proportion of pups that survived to the age of 90 days old (the age at which a pup is considered to be nutritionally independent) over the relevant time period	GLM - Binomial
Litter emergence	The proportion of litters born over the relevant time period where at least one pup survived to emergence from the den at 30 days old.	GLM - Binomial
Sex ratio of pups produced	The ratio of female to male pups born over the relevant time period.	GLM - Binomial

Table 2: Description of the explanatory variables used for this investigation

Explanatory variable	Description
Mean rainfall (mm)	Rainfall is taken as a daily measure which is totalled and turned into a mean value across the relevant time period.
Proportion of days with rainfall	The proportion of days with rainfall across the relevant time period
Mean maximum temperature (°C)	The mean maximum daily temperature over the relevant time period.
Mean minimum temperature (°C)	The mean minimum daily temperature over the relevant time period.
Number of breeding females	A count of the number of females who were of breeding age over the relevant time period.

2.6 Model selection

For each model set, a selection process was carried out to assess which explanatory variable had the greatest impact on the response variable. For each response variable, a null model was created (containing no explanatory variables) alongside the investigatory models. Comparisons of the null AIC values were then made to the other models run. Each model that had lower AIC value than that from the corresponding null model was considered to be an influential climatic variable. Significant results were then presented graphically. To find the most influential explanatory variable, multiple selection tables were created (Tables 3 and 4) these were created via R Studio (R Core Team, 2020). Within these tables were all the significant results one section of models, and from this collective it finds which explanatory variable has the greatest impact on the corresponding response variable. Therefore, only the most influential climatic factors were presented, all other results can be found in the appendices.

2.7 Model checking

For all models, I ran model diagnostic plots to ensure that the residuals were approximately normally distributed. Overall, the residuals showed no clear patterns for any of the models. See Appendix 2 -8 for the residual distribution of each model and for the residual deviance of the fitted values for each model in this investigation. Out of the 25 models run within all sections of this investigation, 15 were found to be overdispersed (the theta value was above 1.5). It is common for overdispersion to be found in Poisson and binomial GLMs as it is the result of empirical variance being greater than the predicted variance (Dean, C.B. and Lundy, E.R., 2014). In our study, this was likely caused by one or more external variables that influence reproduction but that were not included in the investigation. This is common in animal breeding studies, where it is not practicable to measure all variables that may impact breeding (Smith, 2014). To ensure that the 15 models were suitable for use, they were checked by re-running the GLM with *quasi-likelihood* families. Altering the format to the quasi families affords the models a dispersion parameter to correct the higher variance found within. However, when converted the to the quasi families, the 15 models appeared to become over-conservative, with all explanatory variables becoming non-significant. This included the number of breeding females in the population, which should be strong predictor of the number of females carrying to term and the number of pups produced (as neither can occur biologically without breeding females). The over-conservatism of the quasi-family models was likely causing this drop in significance; therefore, I chose to exclude these models and kept the original 15 models.

2.8 Correlated terms

As climatic variables may be correlated with one another, correlation tests were carried out on the explanatory variables used across an average year and the longer-term rainy seasons (Figures 3-5). Including correlated variables in models can reduce their explanatory power (Tu et al., 2005). The monthly data (across an average year) showed that mean monthly rainfall was highly correlated to the proportion of days that experienced rainfall (r = 0.97, figure 3a). These two variables were not included in the same model. There was also a correlation between mean daily rainfall and the proportion of days with rain found across the 38 rainy seasons (r = 0.34, Figure 3b). Both of these variables are linked as rainy days require rainfall; however, they may have opposing biological effects. For banded mongooses, increased rainfall leads to increased invertebrate food supply (Marshall et al., 2017), but banded mongooses do not forage when it is raining (Nichols et al., 2012.). An increasing number of rainy days could therefore have an opposing effect to an increasing total amount of rainfall. Given their relatively low level of correlation and their potentially opposing impacts, I included both variables in the same model, which allows the GLM to compensate for both at the same time.

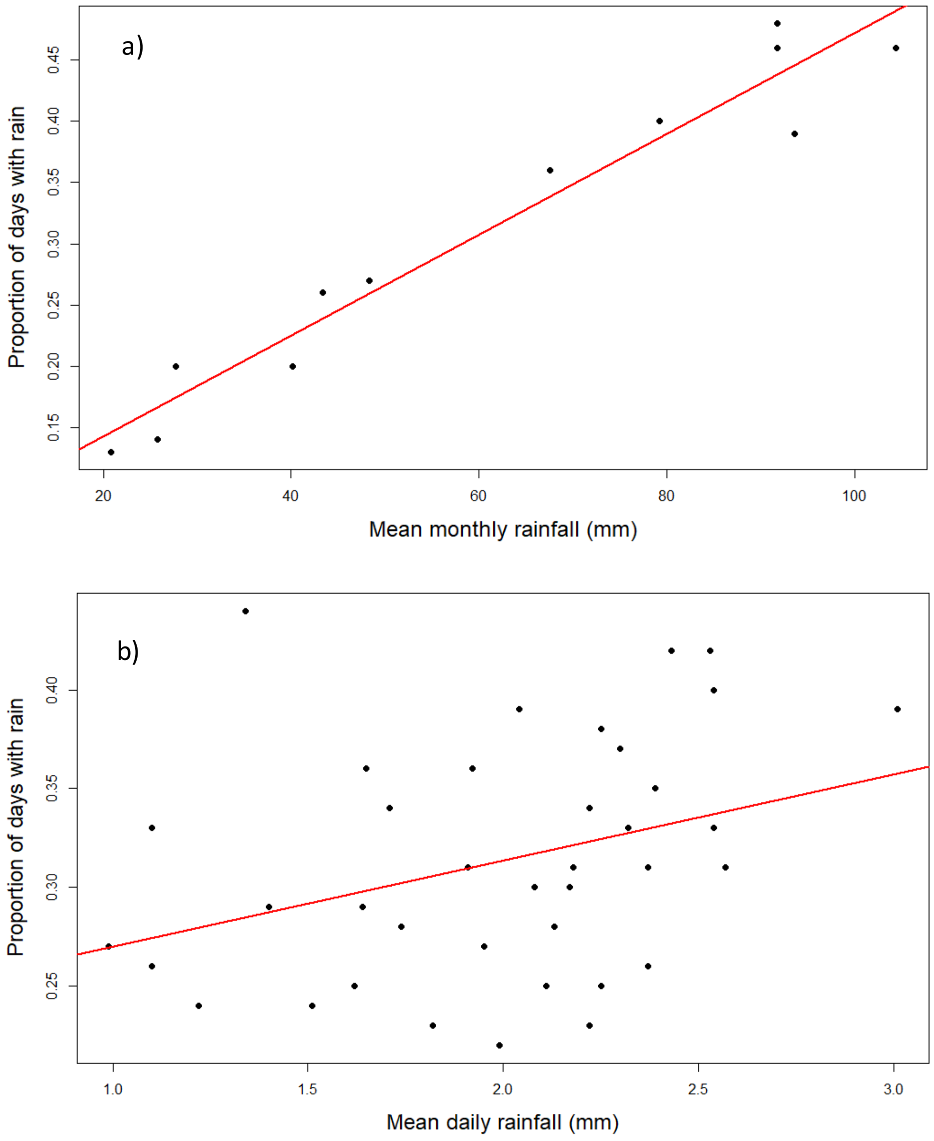

Figure 3: a) correlation between the mean monthly rainfall and the proportion of days with rainfall over monthly periods, b) correlation between the mean daily rainfall and the proportion of days within rainy seasons.

Correlations were also identified between the minimum and maximum temperatures for both the average year and the rainy season data sets. Across the average year the degree of correlation was r = 0.50 (figure 4a) and across the 38 rainy seasons, the value was r = -0.50 (Figure 4b).

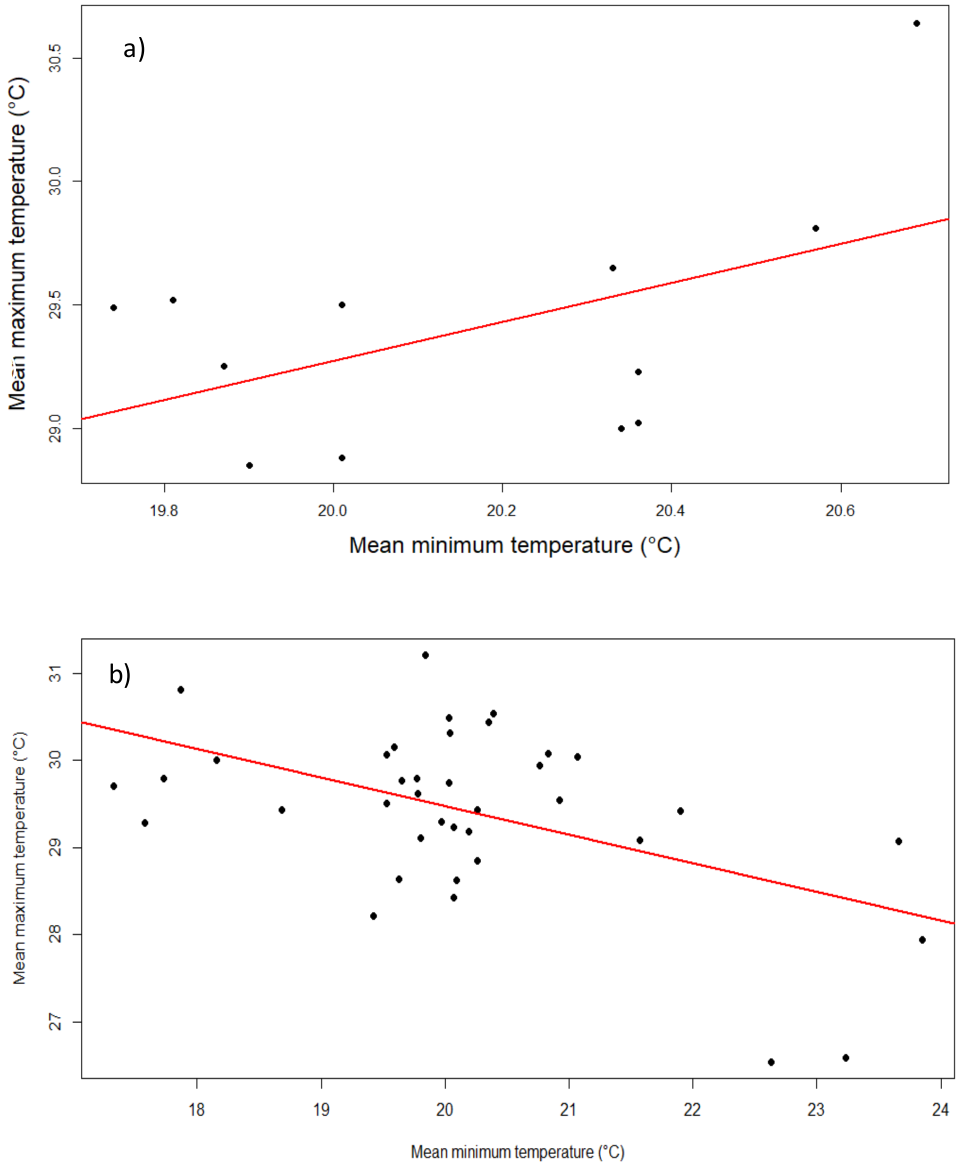

Figure 4: a) correlation between the minimum and maximum temperatures over an average year, b) correlation between mean maximum temperature and the mean minimum temperature within rainy seasons.

Mean monthly rainfall and maximum temperature had a correlation of r = -0.46 (Figure 5a) over an average year, and a similar value was found across the 38 rainy seasons (Figure 5b) as the correlation was r = -0.41. When there are higher temperatures in an environment it is associated with less rainfall, and when these conditions persist it is likely to create droughts and as a result the flora and fauna are negatively affected (Kallis, 2008). The intensity of droughts is a result of positive feedback loops; as it gets hotter more water is removed from the water cycle which further increases the temperature and so on (Lu et al., 2011). Bouts of rainfall can stop this loop as the rain cools the ambient temperature which reduces evaporation return the climate back to a stable state.

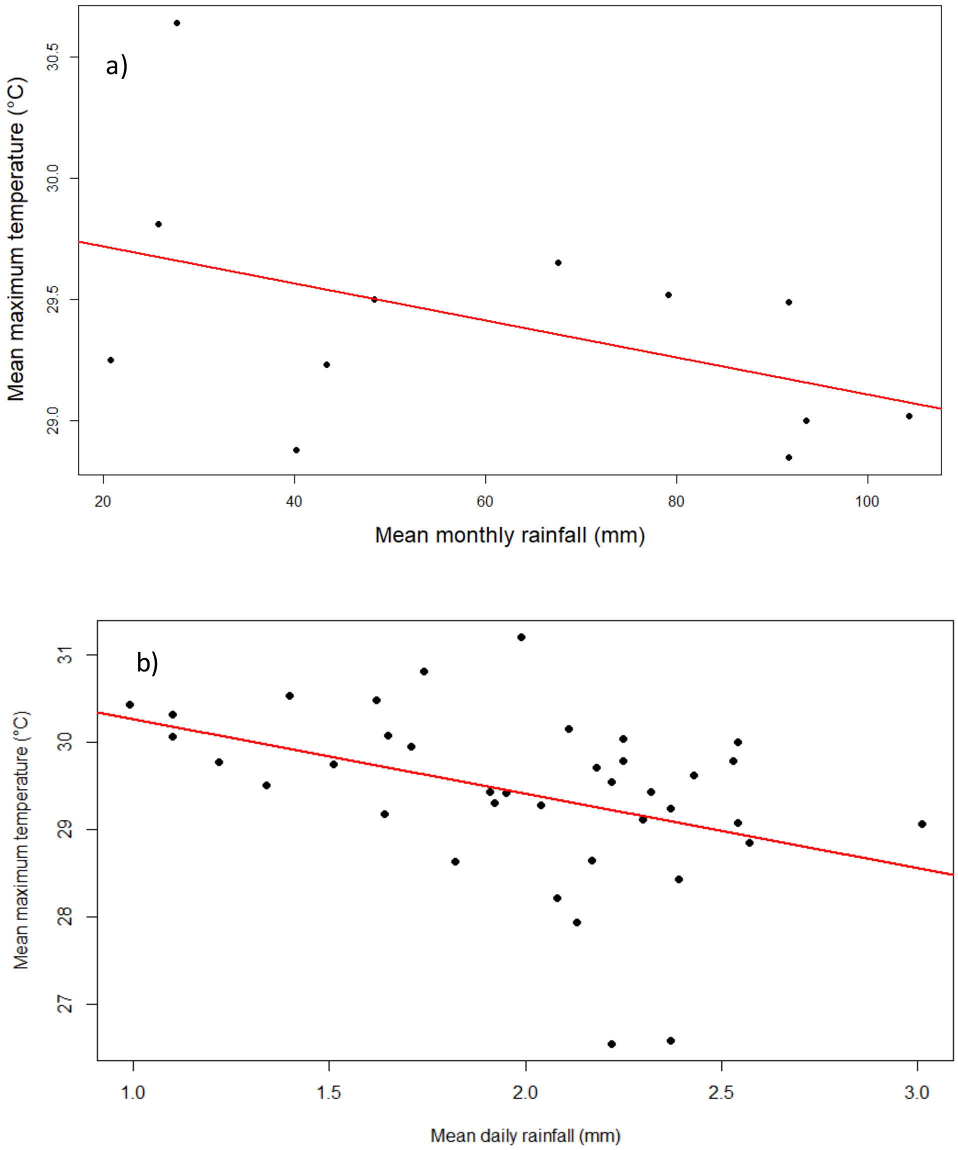

Figure 5: a) correlation between the mean maximum temperature and mean monthly rainfall over an average year, b) correlation between mean daily rainfall and mean maximum temperature within rainy seasons.

3. Results

3.1 – Seasonal effects across an average year

Over an average year, rainfall varied between months (Figure 1) with two peaks in rainfall, one in the first six months of the year (April) and the second in the last six months (November), with reduced rainfall between each peak. The proportion of days experiencing rainfall follows the same pattern (two peaks, one in a separate half of the year), with the largest peak in November. Approximately half the days of the month experience rainfall in November, which is approximately 3.7x larger than the lowest trough in July (Figure 1).

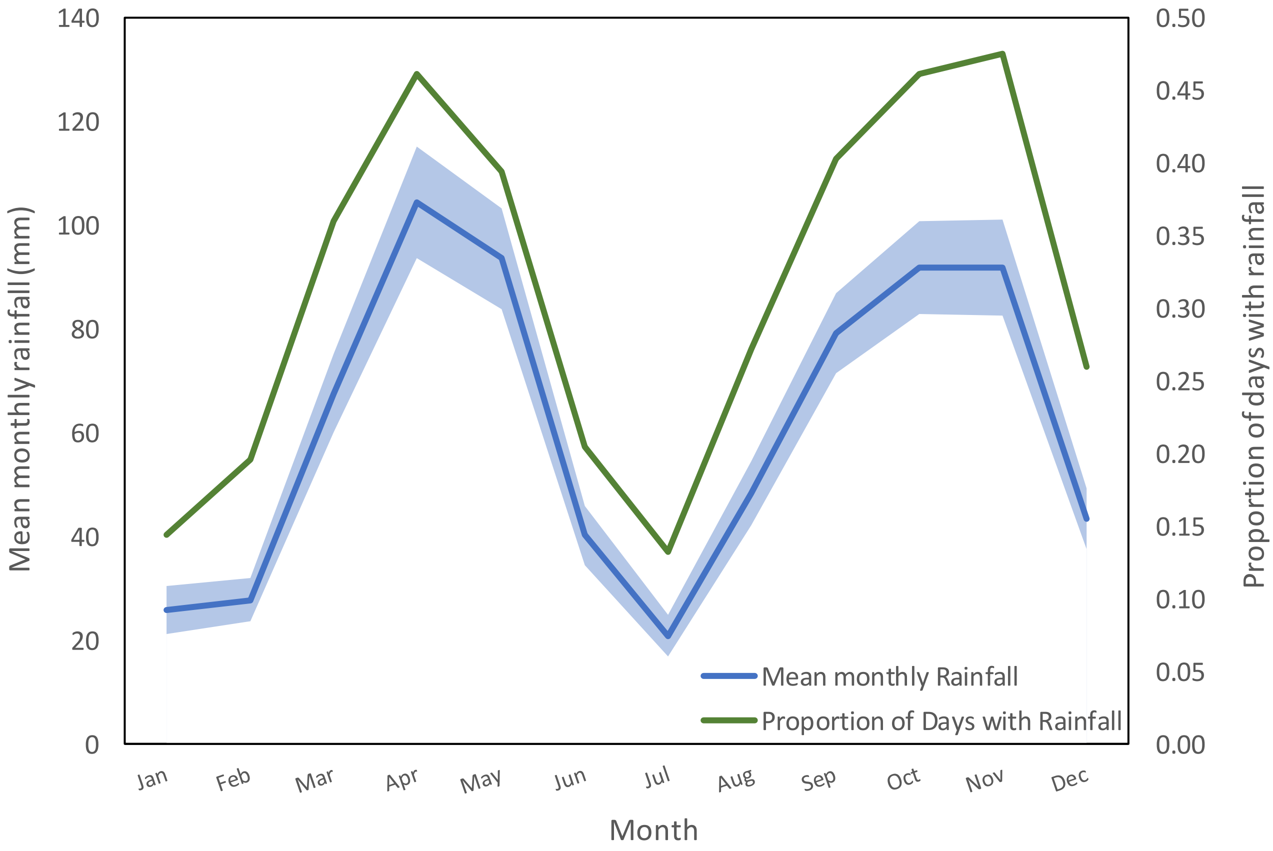

Figure 6: Mean monthly rainfall and proportion of days with rain trend across the year. Blue shading represents the standard error area of mean monthly rainfall (Mm)

The mean minimum and maximum temperature vary little over the course of a year (Figure 7). For the mean minimum temperature, there was no more than a 1°C change in average temperature across all months, whereas the mean maximum temperature varied by approximately 2°C, as seen by the spike in February (30.64°C) and the drop in November (28.85°C). There is a distinct 8.16°C separation between the two temperature boundaries across an average year.

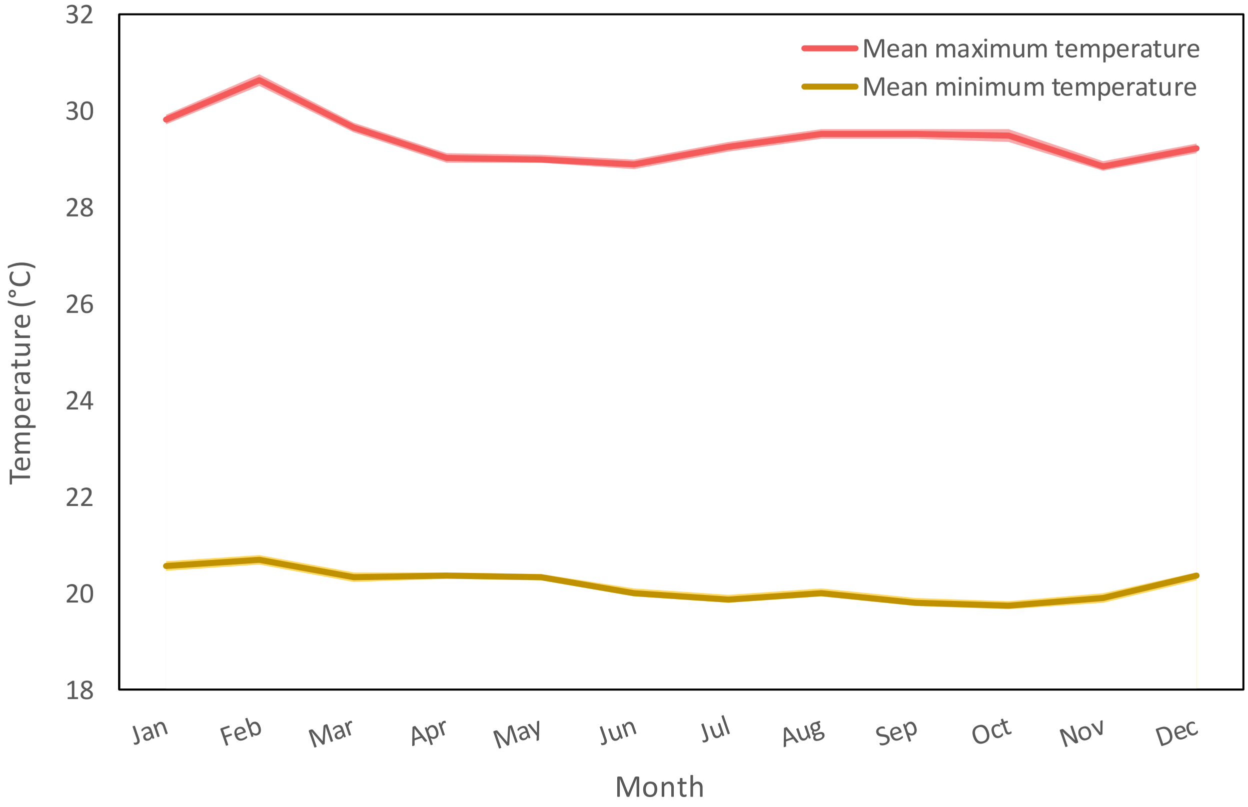

Figure 7: Mean minimum and maximum temperature across a mean year, both with standard error shaded areas.

3.1.1 – Number of females carrying to term across an average year

The model with the lowest AIC included the mean maximum temperature as the best predictor of the number of females carrying pregnancies to term per month (Table 3). Fewer females were found to carry their pregnacies to term in months with higher maximum temperatures (Figure 8, Table 5). The AIC score was 409.61 whch was lower than the null (469.73) and, for this set of results, it is the most influencial climatic factors affecting the reproductive demography (Table 3). All the explanatory variables were significant and are all likely to affect the breeding females in the population; the full set of results are in Table 5 and the full graphical results are in Appendix 1.1.

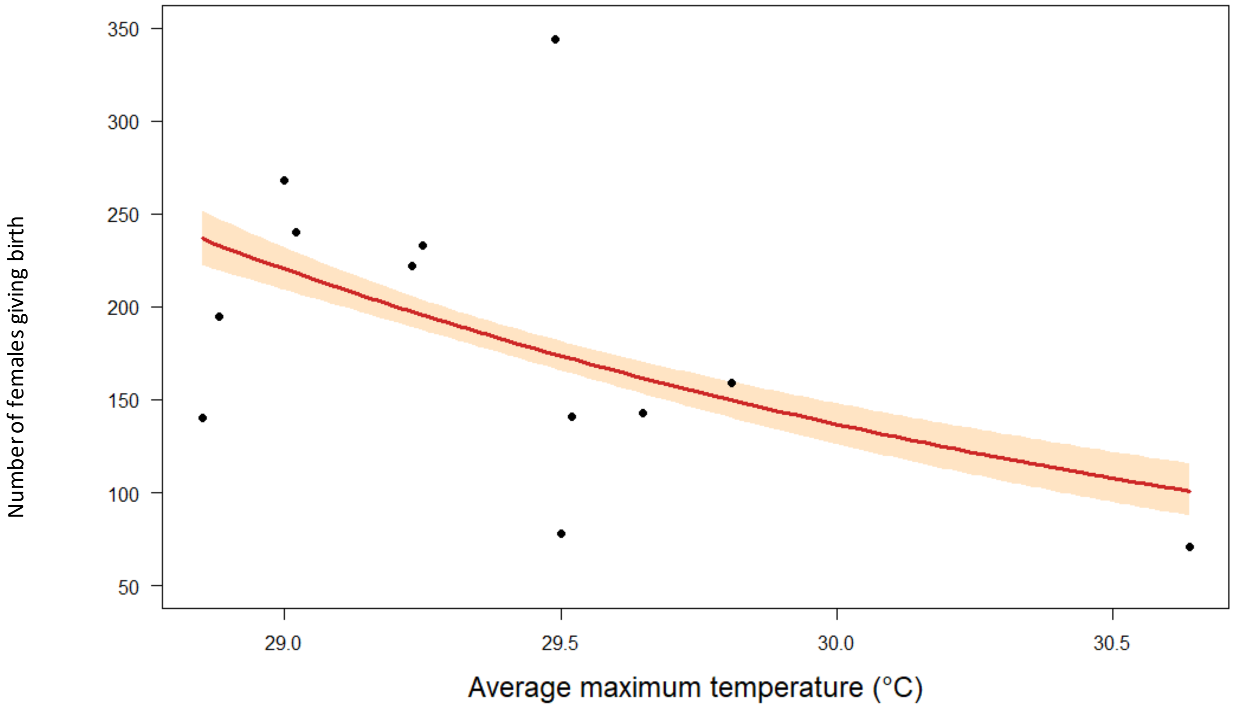

Figure 8: The response of females carrying to term and the mean maximum temperature across an average year. The shaded area corresponds to the 95% confidence limit.

3.1.2 Number of pups produced across an average year

Fewer pups were produced in months with a higher mean maximum temperature (Figure 9, Table 5). The AIC score was 431.96, which was lower than the null for this model set (609.87) and the other significant relationships, indicating that the maximum temperature is the best predictor for the number of pups produced in a month (Table 3). All results from the four models were significant and are likely to affect the number of pups produced, but the mean maximum temperature has the most influence. All results can be found in Table 5 and in appendix 1.1.

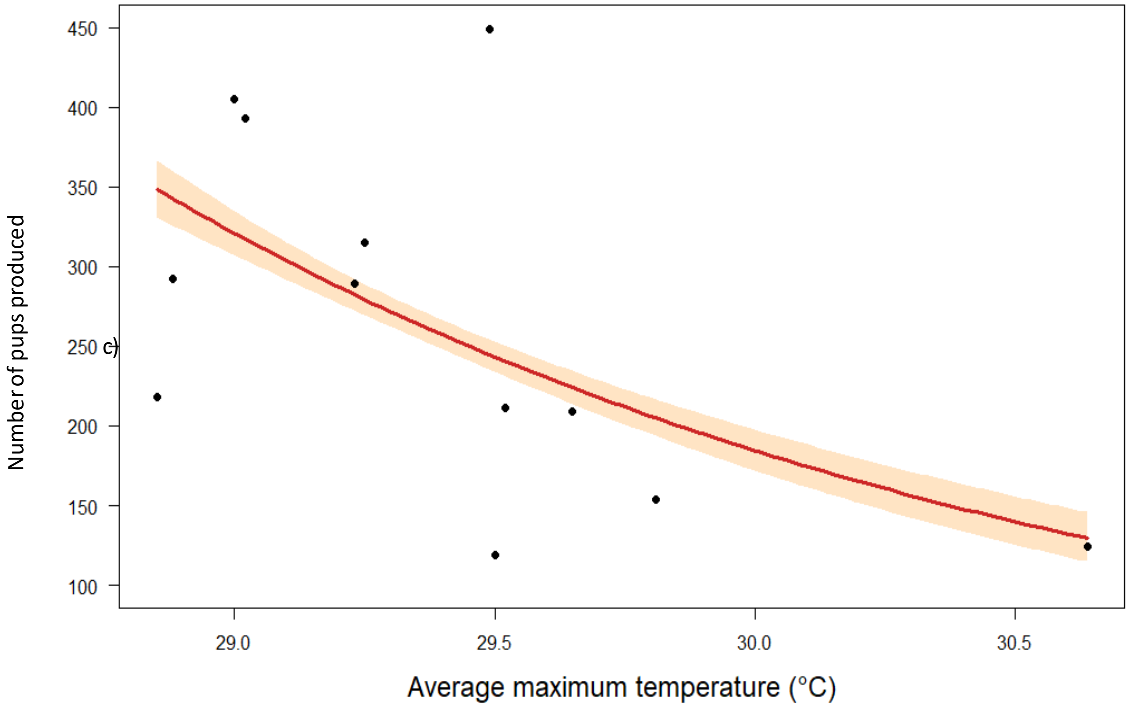

Figure 9: The response between the number of pups being produced and the mean maximum temperature across an average year. The shaded area corresponds to the 95% confidence limits.

3.2 – Climatic conditions across rainy seasons

Across the 38 rainy seasons included in this study, the mean daily rainfall varies greatly (Figure 5). The first six-month period of 2014 shows the highest rainfall at an average of 3.01 mm per day whereas the first season of 2019 has the lowest rainfall at 0.99 mm; this is a difference of over 2mm per day. The proportion of days with rain also varies considerably, with the lowest proportion of rainy days in the first period of 2000, where just under a quarter of the total days had experienced rainfall and the highest in the second period of 2019 being doubled to nearly half the days of the six-month period.

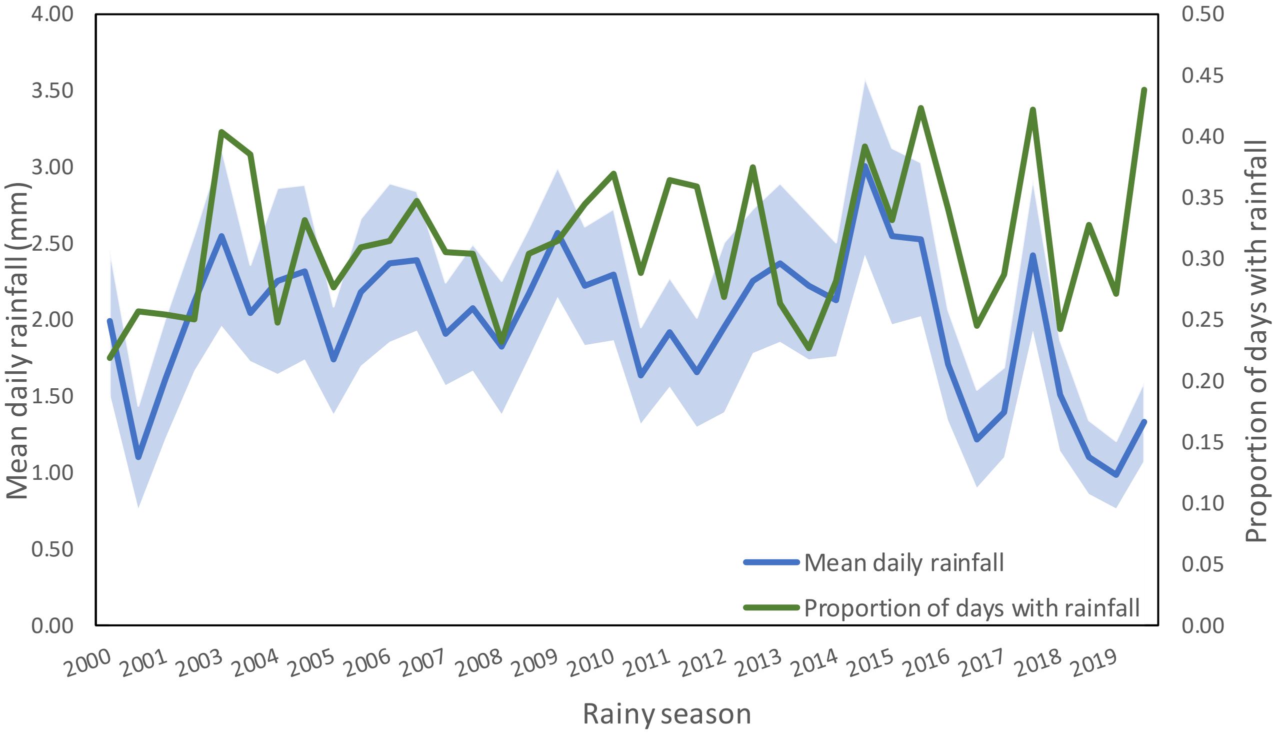

Figure 10: The mean daily rainfall and the proportion of days with rainfall across 38 rainy seasons. The standard error is shown by the blue shaded area around the mean rainfall (mm).

Temperature also varied across the 38 rainy seasons; the mean maximum temperature varied by nearly five degrees, with the highest temperature being 31.21°C in the first rainy season of 2000 and the lowest temperature being 26.54°C in the second season of 2013 (Figure 6). A similar spike was found for the mean minimum temperature 2013 to 2014 where the hottest temperature was recorded at 23.85°C in the first half of 2014. The lowest minimum temperature overall was in the second season of 2005 at 17.33°C.

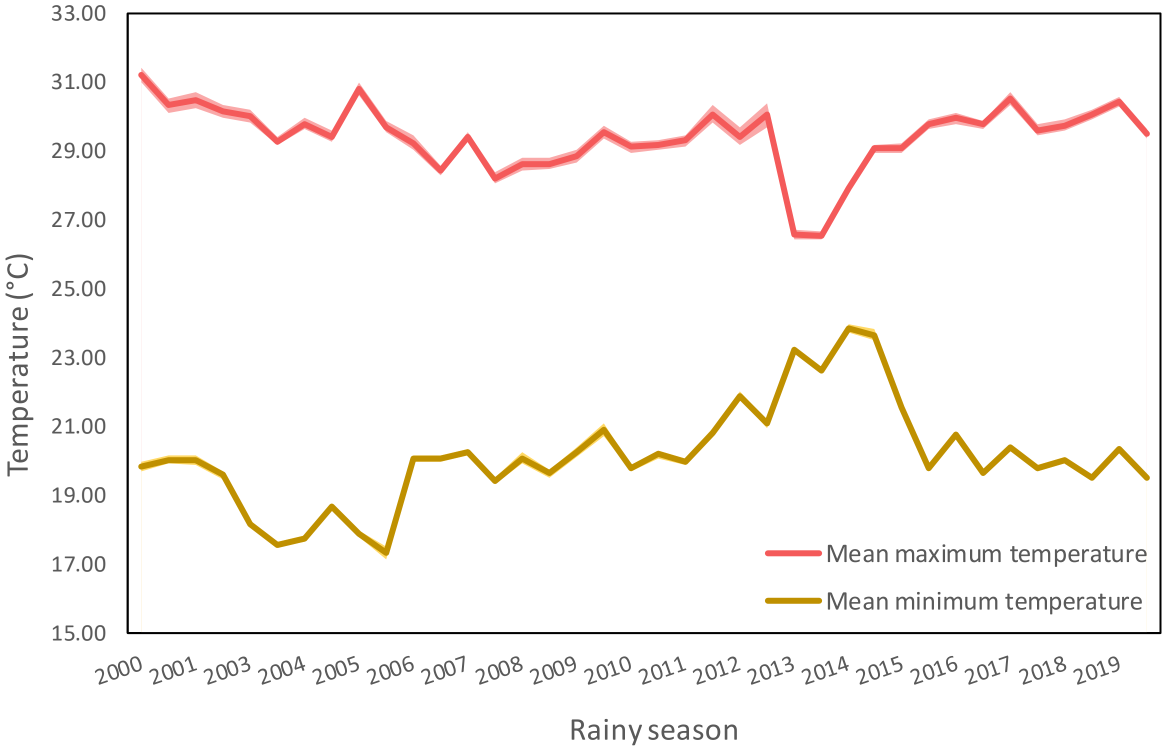

Figure 11: Mean minimum and maximum temperature across rainy seasons, both with shaded standard error areas.

3.2.1 – Number of females carrying to term across rainy seasons

More females carried their pregnancies to term when rainy seasons had a higher mean daily rainfall. The AIC score for this model is 353.51 which was lower than the null model (381.52) and the alternative models including the temperature variables (361.63) indicating that this environmental variable is the most influential (Table 4). I found no effect of the proportion of days that experienced rainfall, or the mean maximum and minimum temperature on the number of females carrying to term in the population (Tables 3 & 5).

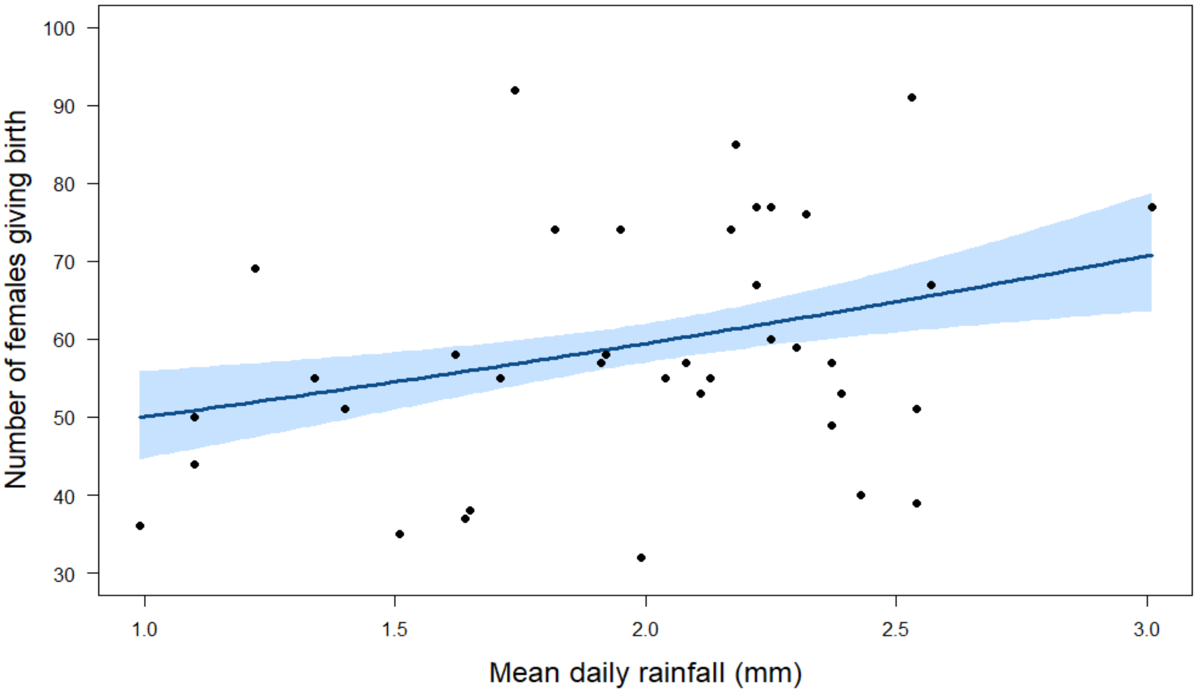

Figure 12: The response of the number of females carrying to term and the mean daily rainfall across rainy season. The shaded area corresponds to the 95% confidence limits.

3.2.2 – Number of pups produced across rainy seasons

A larger number of pups were produced in the population during rainy seasons with a greater mean daily rainfall (Figure 13), and fewer were produced when seasons had higher minimum temperatures. The best predictor for this reproductive parameter was mean daily rainfall as it had the lower AIC (454.19) which was lower than the null (467.81) and the temperature model (463.45). The full set of results can be found in Table 4 and Appendix1.2. No relationship was found between the number of pups born and the proportion of days with rainfall or the mean maximum temperature within a season (Table 5).

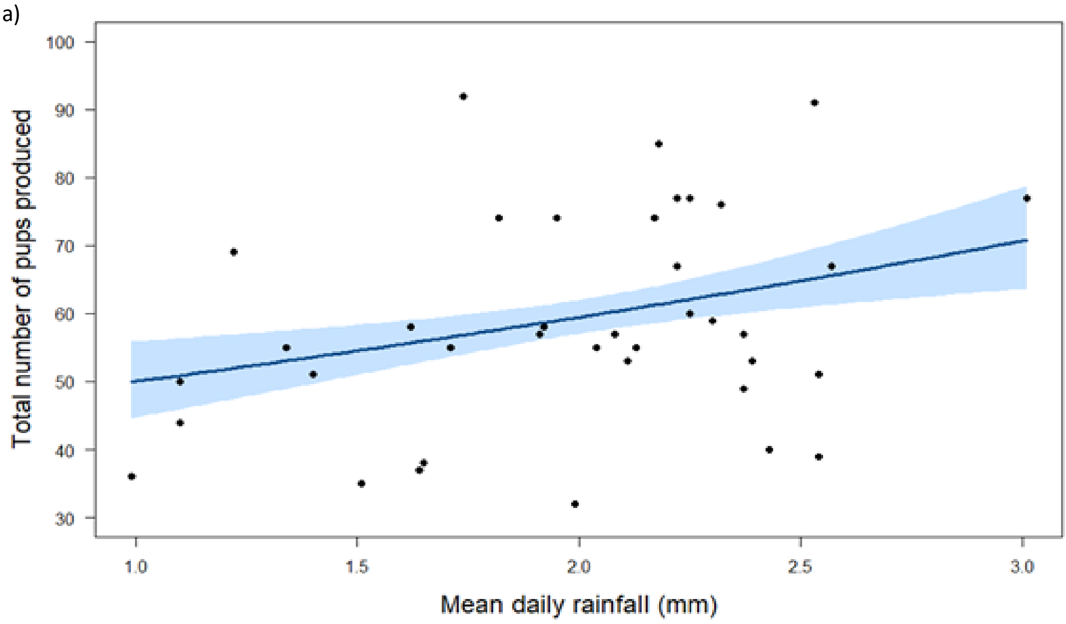

Figure 13: The relationship between the number of pups being produced and the mean daily rainfall across rainy seasons. The shaded area corresponds to the 95% confidence limits, with raw data plotted.

3.2.3 - Proportion of pups surviving to independence across rainy seasons

A smaller proportion of pups survived to 90 days in rainy seasons with a higher mean daily rainfall (Figure14a), while the opposite relationship was found for the proportion of days with rainfall as more pups were surviving with a greater number of days that experienced rainfall (Figure 14a and b respectively). The AIC score for this model (383.42) was lower than the null model (427.93) and the model including temperature variables (422.42), making it the best model in this set. All results can be found in Table 5.

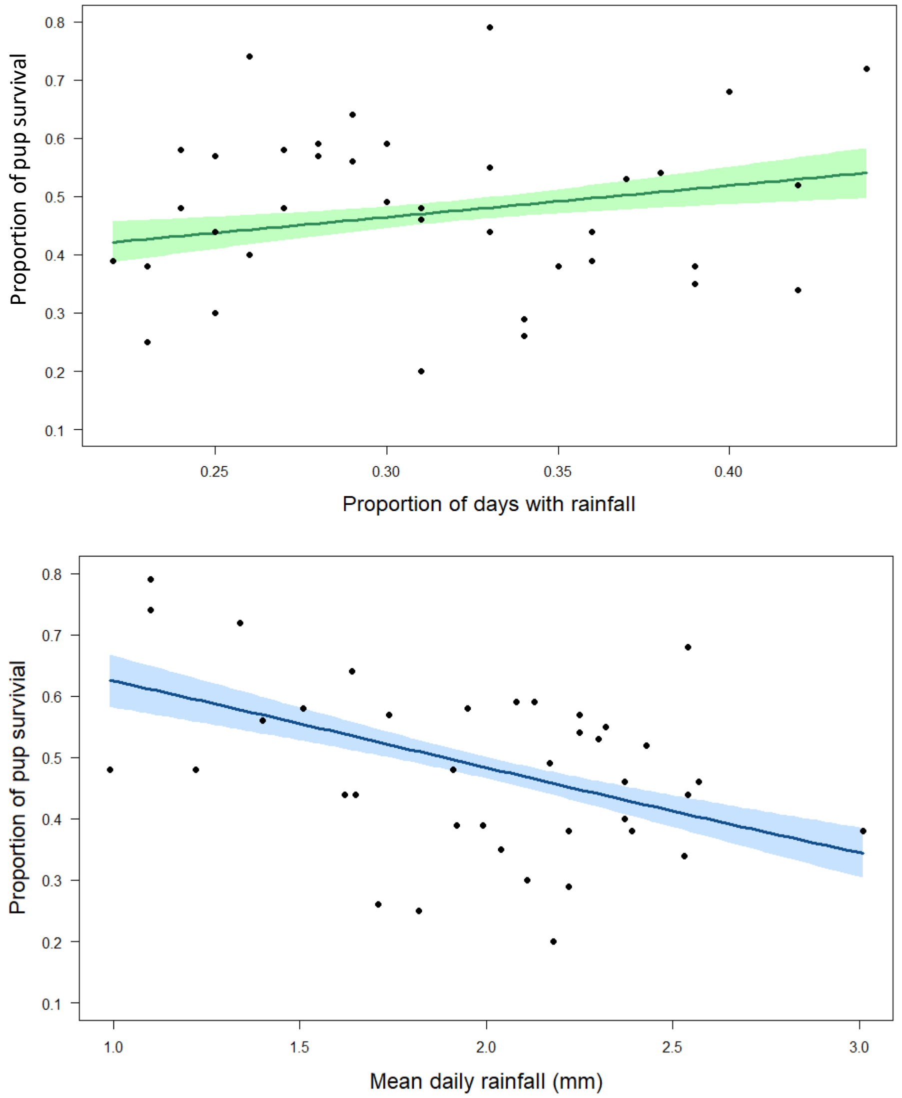

Figure 14 : The relationship of pup survival to 90 days with the mean daily rainfall, and the proportions of days with rainfall. The shaded area corresponds to the 95% confidence limits.

3.2.4 – Proportion of females born across rainy seasons

There was a smaller proportion of female pups produced into the population when the mean maximum temperature of a rainy season increased (Figure 15). The AIC for the best performing model (including temperature variables) was 173.76, which is smaller than the null model (214.31) and the alternative model including rainfall variables (217.29), making it the best predictor for this model set. No effect was found between the proportion of female pups and the mean daily rainfall (mm), proportion of days with rainfall and mean minimum temperature (°C) (Table 5).

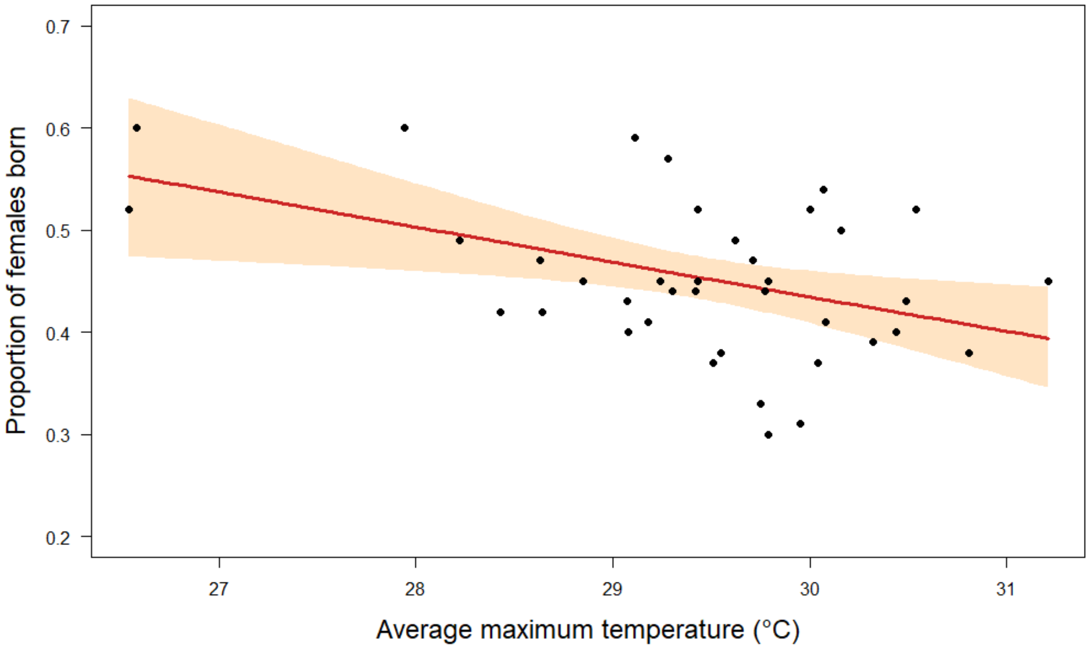

Figure 15: The relationship of the proportion of females born to the mean maximum temperature. The shaded area corresponds to the 95% confidence limits.

3.2.5 – Proportion of litter emergence across rainy seasons

For the proportion of litters that emerged within the study population, I found that there were no relationships to any of the explanatory variables across rainy seasons (Table 6), with the null model producing the lowest AIC score.

3.2.5 – Influence of droughts across rainy seasons

I found no evidence that droughts (hot, dry conditions) had a particularly negative impact on banded mongoose reproduction; there were no significant interactions between temperature and rainfall on any reproductive parameter (Table 7).

Table 3: Model selection table for the two reproductive parameters across the average year.

Response variable	Explanatory variable	Model number	AICc	Evidence ratio
Number of females giving birth	Mean max temperature	3	376.46	1.000000e+00
	Mean monthly rainfall	1	410.94	3.085142e+07
	Proportion of days with rainfall	2	437.13	1.496611e+13
	Mean minimum temperature	4	437.80	2.101932e+13
	N/A	Null	470.13	2.196668e+20
Number of pups produced	Mean max temperature	3	433.29	1.000000e+00
	Mean monthly rainfall	1	456.27	9.77548e+04
	Proportion of days with rainfall	2	511.46	9.420517e+16
	Mean minimum temperature	4	565.18	4.345983e+28
	N/A	Null	610.25	2.688352e+38

Table 4: model selection table for the two reproductive parameters across rainy seasons.

Response variable	Explanatory variable	Model number	AICc	Evidence ratio
Number of pups being produced	Mean daily rainfall & proportion of days with rainfall	1	454.41	1.000000
	Mean maximum and minimum temperature	2	454.65	1.131187
	N/A	Null	467.81	812.950966
Proportion of pups surviving to 90 days	Mean daily rainfall and proportion of days with rainfall	1	384.13	1
	Mean maximum and minimum temperature	2	423.12	293808579
	N/A	Null	428.05	3441719951

Table 5: All model results from the average year data, with an asterisk to highlight significant relationships.

Response variable	Explanatory Variables	Model number	Estimate	Standard error	Z value	P value	AIC Value	Intercept Value
Number of females giving birth	N/A	Null	5.22664	0.02116	247	<2x10^{-16}	469.73	N/A
	Rainfall (mm)	1	0.005768	0.000735	7.848	4.22e-15 *	409.61	<2e-46
	Days with rain (%)		1.04129	0.17454	5.966	2.43e-09 *	435.80	<2e-16
	Max temp (°C)	2	-0.47638	0.05072	-9.393	<2x10^{-16} *	375.12	<2e-16
	Min temp (°C)		-0.42205	0.07154	-5.899	3.65e-09 *	436.47	<2e-16
Number of pups produced	N/A	Null	5.57910	0.01774	314.5	<2x10^{-16}	609.87	N/A
	Rainfall (mm)	1	0.0077135	0.0006207	12.43	2.43x10^{-09} *	454.93	<2e-16
	Days with rain (%)		1.47560	0.14755	10.00	<2x10^{-16} *	510.13	<2e-16
	Max temp (°C)	2	-0.55263	0.04342	-12.73	3.65x10^{-09} *	431.96	<2e-16
	Min temp (°C)		-0.41287	0.05995	-6.886	5.72x10^{-12} *	563.84	<2e-16

Table 6: All model results from the rainy season data, with an asterisk to highlight significant relationships.

Response variable	Explanatory Variables	Model number	Estimate	Standard error	Z value	P value	AIC Value	Intercept Value
Number of females giving birth	N/A	Null	4.07396	0.02116	192.6	<2e-16	381.52	N/A
	Rainfall (mm)	1	0.172982	0.051117	3.384	0.000714 *	353.51	<2e-16*
	Days with rain (%)		-0.502083	0.386164	-1.300	0.193540		
	Number of breeding females		0.008293	0.002147	3.862	0.000112 *		
	Max temp (°C)	2	-0.026212	0.028158	-0.931	0.3519	361.63	7.29e-06
	Min temp (°C)		-0.032173	0.016964	-1.896	0.0579		
	Number of breeding females		0.008845	0.002258	3.918	8.9e-05 *		
Number of pups produced	N/A	Null	4.42642	0.01774	249.5	<2e-16	467.70	N/A
	Rainfall (mm)	1	0.095643	0.042419	2.255	0.024153 *	453.19	<2e-16*
	Days with rain (%)		-0.467753	0.323348	-1.447	0.147010		
	Number of breeding females		0.005978	0.001799	3.323	0.000891 *		
	Max temp (°C)	2	-0.038021	0.023470	-1.620	0.1052	453.44	2.04e-10
	Min temp (°C)		-0.032854	0.014221	-2.312	0.0208 *		
	Number of breeding females		0.005356	0.001895	2.827	0.0047 *		

Pup survival to 90 days	N/A	Null	-0.06673	0.03550	-1.88	0.0601	427.93	N/A
	Rainfall (mm)	1	-0.57366	0.08424	-6.810	9.75x10-12 *	383.42	0.059001
	Days with rain (%)		2.13414	0.65918	3.238	0.00121 *		
	Number of breeding females		2.17401	0.65935	3.297	0.000977 *		
	Max temp (°C)	2	0.11011	0.044031	2.521	0.0117 *	422.42	0.0647
	Min temp (°C)		-0.009743	0.026969	-0.361	0.7179		
	Number of breeding females		-0.01062	0.02697	-0.349	0.6937 *		
Litter emergence	N/A	Null	0.75492	0.08489	8.893	<2e-16	171.42	N/A
	Rainfall (mm)	1	-0.3669	0.2085	-1.760	0.0785	172.20	0.0131*
	Days with rain (%)		0.5651	1.5448	0.366	0.7145		
	Max temp (°C)	2	-0.13065	0.10371	-1.260	0.208	173.76	0.140
	Min temp (°C)		-0.05721	0.06633	-0.862	0.388		
Sex ratio of pups	N/A	Null	-0.18431	0.04273	-4.313	1.61e-05	214.31	N/A
	Rainfall (mm)	1	0.09448	0.09975	0.947	0.344	217.29	0.423
	Days with rain (%)		-0.52680	0.80593	-0.654	0.513		
	Max temp (°C)	2	-0.13772	0.05403	-2.549	0.0108 *	173.76	0.0303
	Min temp (°C)		-0.02308	0.03254	-0.709	0.4781		

Table 7: Results table showing the interactions between mean daily rainfall and mean maximum temperature across seasons.

Response variable	Explanatory variables	Model number	Estimate	Standard error	Z value	P value	AIC Value	Intercept Value
Number of females giving birth	N/A	Null	4.07396	0.02116	192.6	<2e-16	381.52	N/A
	Mean daily rainfall (mm)	1	-3.16755	2.41707	-1.310	0.1900	367.52	0.0393
	Mean maximum temperature		-0.23934	0.17573	-1.362	0.1732		
	Mean daily rainfall: Mean maximum temperature		0.11303	0.08115	1.393	0.1637		
Number of pups produced	N/A	Null	4.42642	0.01774	249.5	<2e-16	467.70	N/A
	Mean daily rainfall (mm)	2	-2.48631	2.00472	-1.240	0.2149		0.0192
	Mean maximum temperature		-0.19978	0.14564	-0.372	0.1701		
	Mean daily rainfall: Mean maximum temperature		0.08673	0.06728	1.289	0.1974		

Pup survival to 90 days	N/A	Null	-0.06673	0.03550	-1.88	0.0601	427.93	N/A
	Mean daily rainfall (mm)	3	3.6407	4.1679	0.874	0.382	395.02	0.335
	Mean maximum temperature		0.3176	0.2993	1.061	0.289		
	Mean daily rainfall: Mean maximum temperature		-0.1377	0.1401	-0.983	0.326		
Litter emergence	N/A	Null	0.75492	0.08489	8.893	<2e-16	171.42	N/A
	Mean daily rainfall (mm)	4	2.97140	10.13853	0.293	0.769	171.07	0.979
	Mean maximum temperature		0.07512	0.73407	0.102	0.918		
	Mean daily rainfall: Mean maximum temperature		-0.11599	0.34046	-0.341	0.733		
Sex ratio of pups	N/A	Null	-0.18431	0.04273	-4.313	1.61e-05	214.31	N/A
	Mean daily rainfall (mm)	5	0.98561	5.01196	0.197	0.844	213.70	0.895
	Mean maximum temperature		-0.05320	0.35909	-0.148	0.882		
	Mean daily rainfall: Mean maximum temperature		-0.03425	0.16836	-0.203	0.839		

4. Discussion

4.1 – Within-year reproductive trends

The aim of this thesis was to investigate the possible impacts that climate change has on the reproductive demography of a banded mongoose population in Uganda. Across an average year there are two identifiable peaks in monthly rainfall and the proportion of days experiencing rainfall (Figure 6), unlike mean maximum and minimum temperature that remained relatively constant. Banded mongoose breeding coincided with seasonal changes in rainfall and temperature. More females carried to term and the number of pups produced increased in months with greater rainfall (mm) and in months that had a larger proportion of wet days (Appendix 1.1 Figures 1& 2, Table 5). This indicates that banded mongooses match their breeding events to the two peaks of rainfall within a year. This is common with other species found in hotter climates. Meerkats have been found to match breeding events to just before the peak rain in a season (Clutton-Brock, 2001). This ensures that food is available for the breeding females, new and when the females are recovering (Doolan and Macdonald, 2009).

With regards to temperature, I found that breeding rates decreases in months that were generally hotter; fewer females carried to term and fewer pups were produced in months that had both higher maximum and minimum temperatures (Figures 8 & 9, Table 5). The most influential climatic variable affecting the reproductive parameters was the maximum temperature (Figure 8). A behavioural trait that banded mongooses use to cope with the hottest part of the day is to rest the middle of the day to avoid overheating (Hodge, 2005). When exposed to high ambient temperatures, mammals struggle to maintain and regulate a body temperature of approximately 37°C without suffering hyperthermia from carrying out normal daily activities (Schlader and Vargas, 2019). As metabolic reactions control the internal body temperature, heat dispersion becomes less effective when energy is exerted by moving or eating which leads to body functions failing, which left uncontrolled can lead to cell damage or death (Lepock, 2003). Philippine tarsiers (*Tarsius syrichta*) have adapted their behaviour so that daytime resting phases are much longer in higher temperatures to reduce the risk of hyperthermia (Lovegrove et al., 2014). Resting is beneficial as it reduces the chance of suffering heat stress. It is likely that banded mongooses in months with higher ambient temperatures are resting for longer amounts of time to avoid the additional heat stress. The benefit of resting and avoiding increased temperatures likely comes at a cost as it results in less time for forging which for breeding individuals is key to successful pregnancies as food availability and consumption plays a large part in body condition, survival and on the breeding success of individuals (Boutin, 1990). No data has yet been collected on the resting period of banded mongooses in our study population, but it would be something to test in future studies because if more time is spent resting less time is spent carrying out other activities such as foraging.

4.2 - Across year reproductive trends

As I found that banded mongooses time their reproduction to coincide with the rainy seasons (which occur twice per year), I then went on to investigate whether environmental variation between the 38 rainy seasons I had data on impacts on banded mongoose reproduction. In total significant relationships were found for four out of the five reproductive parameters. The only parameter that had no connection to any of the climatic variables was the proportion of litters that emerged over a season. A significant positive relationship was found between the mean daily rainfall (mm) of a season and the number of females that carried to term, and also between mean daily rainfall and the number of pups produced in the population (Figure 12 & 13). During pregnancy, females require more food to maintain higher body condition as it is for both their own maintenance and to counteract the high energetic costs of pregnancy (Stockley and Bro-Jørgensen, 2011). Gestation and lactation have high energy requirements, for example in female ungulates, energy costs are approximately 50% higher in pregnant females than non-breeding females (Parker et al., 2009). Perrigo (1987) found that captive female deer mice (*Peromyscus maniculatus)* that gathered more food maintained a greater body weight and had more successful pregnancies. In Marshall et al. (2017), discovered that after rainfall occurs invertebrate abundance increases, and as a result banded mongooses can find food in higher quantities. The rate of food intake is therefore likely to be at higher in seasons with higher levels of rainfall, which will influence the body condition of the females, and therefore minimise the cost of pregnancy.

Banded mongoose females breed in cohorts of up to eight females, so a lot of resources are needed to support these groups. If there are not enough resources, evictions will occur whereby dominant females forcibly evict subordinates from the social group (Cant et al., 2010). Evictions cause subordinate females to abort their pregnancies so that they can return to their social and familial group (Cant et al., 2010, Inzani et al., 2019). This eviction process can greatly reduce the number of pups produced in a population as multiple females can be forced from the group, especially when resources are low. Additionally spontaneous abortion frequency increases when the females are unable to support their pregnancy. This can be a result of malnutrition, environmental stressors, and social pressure from males (Creel and Creel, 1991). My results suggest that in rainy seasons with greater rainfall there is a greater abundance of resources and hence lower levels of competition between females for the resources required to support reproduction. This lack of competition between the dominant and subordinate females allows for more pregnancies to be carried to term, and therefore pups are birthed on a greater scale.

An interesting result from my study was that rainfall was negatively associated with pup survival to independence at 90 days old. Stochastic events such as thunderstorms have been seen to cause flooding of underground dens in slender-tailed meerkat populations (Doolan and Mcdonald, 2009). With more rainfall there is a higher chance of flooding events which may pose a threat to the banded mongoose pups at the early stages of life. While it may affect pups still in the den, flooding is unlikely to explain why pups once emerged would be negatively impacted by higher rainfall. A possible explanation for decreased pup survival is that there is there is a potential lack of escorts for all the pups produced when rainfall is higher. When pups leave the den the are escorted by a single adult until they reach independence at 90 days old. During this time the adult will teach the pup to forage and how to defend itself from predators (Bell, 2007). With an increasing ratio of pups to adults it is possible that more pups are left with no escort. Without this protection and behavioural development, it places unescorted pups at risk from malnourishment and predation (Gilchrist, 2004). Additionally, the rate of pup survival increased when there was a greater proportion of days that experience rainfall. Banded mongooses do not forage during periods of rain as they take shelter, which may reduce the amount of time spent for possible foraging opportunities (Rood, 1975). However, if there are more days with rainfall it is more likely that days that had rainfall would likely be experiencing short showers that occur more frequently, than heavy downpours that last for longer lengths of time. This could offset the amount of time that individuals spend taking shelter from rain. This would only hinder foraging for a short amount of time during the day rather than losing a whole days' worth of foraging as a result of a prolonged downpour. It would also mean that higher invertebrate abundance may last longer providing more food for the pups and further increasing the proportion surviving to 90 days.

My analysis of sex ratio found that a reduced proportion of female pups were born into seasons with a higher mean maximum temperature (Figure 15). The influence of temperature on sex determination is well understood in many reptile species. Green sea turtle (*Chelonia mydas*) embryo sex is determined in the second third of incubation, when the sex of the hatchling is permanently decided (Laloë et al., 2017). When temperatures are high at nesting sites, the sex ratio of the eggs are skewed towards females and in cooler climates it is favoured towards males (Packard et al., 1977). In mammals, Sex determination is pre-determined by the genetics of the embryo and is not affected by the environment like reptiles (Lolavar and Wyneken, 2019). A more likely explanation as to why the maximum temperature impacts the proportion of females born in the population is that environmental conditions can create stress responses in male and female adults before, during and after parturition. In domestic animals, high environmental temperatures can lead to heat stress, which can impact biological processes; high temperatures have been shown to lead to delayed puberty, irregularities with cycle length, ovulation rate and altered gamete characteristics (Hafez, 1964, Takahashi, 2012). These temperature-related changes can have subsequent impacts on sex ratio. Hansen (2009) conducted a study on different domestic animals and found that when males were exposed to higher temperatures, they produced sperm with higher abnormal and mutated characteristics. Embryos produced from this damaged sperm were skewed towards female (Pérez-Crespo et al., 2005). Owners of domestic animals can easily implement measures to avoid reproductive problems i.e., shaded, or ventilated barns to mitigate the impact of heat stress on their animals (Vitt et al., 2017). However, the lack of convenient and readily available methods of cooling in the wild, bar resting and drinking it is possible that when temperatures are high resultant to embryo or sperm death is sex-biased, leading to a skewed pup sex ratio.

Unlike the other reproductive variables I investigated, I found no association between the proportion of litters surviving to 30 days (emergence from the den) and environmental conditions. It is likely that biological factors play a much larger role than environmental conditions. Infanticide regularly occurs within dens before emergence occurs as dominant females terminate litters that are not synchronised with the birth of their own litter to maximise their own reproductive success (Gilchrist, 2006). Predation may also cause litter death before emergence; banded mongooses, meerkats, and dwarf mongooses (*Helogale parvula)* all share the same denning strategy (Doolan and Macdonald 2009; Rood, 2010; Cant et al., 2013). Underground dens are vulnerable to ground predators such as the Cape cobra

(*Naja nivea*) which will evade foraging adults to gain access to dens to predate on litters (Doolan and Macdonald, 1999).

Unfortunately, without excluding all external factors such as predation, disease, and stochastic events it is difficult to understand the full extent in which climate change plays a role on the emergence of litters in the population.

4.3 Interactions with maximum temperature and daily rainfall across seasons

Finally, I investigated the impact of droughts on the reproductive parameters by modelling the potential interactions between rainfall and temperature variables on reproductive variables. High temperatures and reduced rainfall are the two drivers behind droughts (Botai et al., 2016). Hot equatorial regions like Uganda have a higher risk of droughts as high temperatures are prevalent throughout the day. When maximum temperatures rise it fuels the formation of droughts (Lu et al., 2011). However, I found no significant interactions between temperature and rainfall on any of the response variables (Table 7) indicating a lack of evidence that hot, dry conditions have any greater impact on the reproduction of banded mongooses when combined than when one is present without the other. However, this may change if climate change leads to more intense droughts than have been recorded at the study site over the 19-year period of my study.

Currently, banded mongooses are classed as a species of least concern under the IUCN Red List as the population trend is classed a stable (Gilchrist et al., 2016). The justification behind this decision is based heavily on the fact the distribution range of the species is wide (Western, Central and Eastern Africa), and that it is found in protected areas throughout range such as the study population (Gilchrist et al., 2002). The main threat to the species comes from human influences such as hunting and trapping (Gilchrist et al., 2016). In multiple regions, banded mongooses are hunted for bush meat by locals, but there are now links between the consumption of banded mongoose meat and the disease leptospirosis, so hunting may decrease as a result of this (Jobbins et al., 2014). No threat from climate change has been identified thus far except for a possible lack of water, however there is a lack of research on the potential impacts of climate change on this species. My study indicates that there are relationships between the climate and the reproductive demography of the banded mongooses that may threaten the species in the future.

A possible future addition to this study would be to quantify population growth rate by highlighting both death and birth rate to test against the climatic variable to test is there is a threshold at which either is heavily influenced by the climate. By using the projected climate from the International Panel on Climate Change (IPCC) scenarios, future studies could predict how the future population will be impacted (IPCC, 2021: Summary for Policymakers). Under the 2021 summary the IPCC has identified three possible outcomes; near term (2021 – 2040), mid-term (2041 – 2060) and long term (2081 -2100) climate outcomes (Masson-Delmotte et al., 2021: Summary for Policymakers). Each scenario depicts the worst outcome if no changes are made to stop climate change for each scenario there are different degrees of change and possible outcomes. Using information such as this would make predicting impacts on the population easier and identify the high risks the future population may face. My study indicated that across a year the biggest climatic influence was maximum temperature of a month. If the IPCC future projections are correct, global temperatures are going to continue to rise over future decades. Combining these predicted climate outcomes and a population viability analysis would be the best method to determine that if the relationships found in this study could potentially lead possibly extinction of banded mongooses if actions are not taken.

5. Conclusion

This study set out to understand the possible impacts of climate change on the reproductive demography of banded mongooses. Overall, rainfall and/or temperature impact the number of females giving birth, the number of pups produced, survival of pups to independence, and the sex ratio of pups in the population. As global temperatures increase, the number of births and the number of pups entering the population is likely to reduce, leading to a potential reduction in population size. This reduction in pup recruitment into the adult population may be, to some extent, offset by the increased survival of pups that are born, but this may not fully compensate for the reduced number of pups entering the population. I expect that higher maximum temperatures will occur in the future and that high temperatures will occur at a greater frequency, which will influence population structure. It will likely lead to a decrease in females having successful pregnancies which will therefore decrease the pup production of populations. Additionally, the sex ratio of social groups may become skewed towards males which could further reduce the reproductive success of banded mongooses. Understanding how climate change influences the reproduction of a species is vital in creating a comprehensive conservation plan that would mitigate the impacts on the population in harsh undesirable conditions.

6. Appendices

Appendix 1.1: Significant relationships for the number of females carrying to term across an average year.

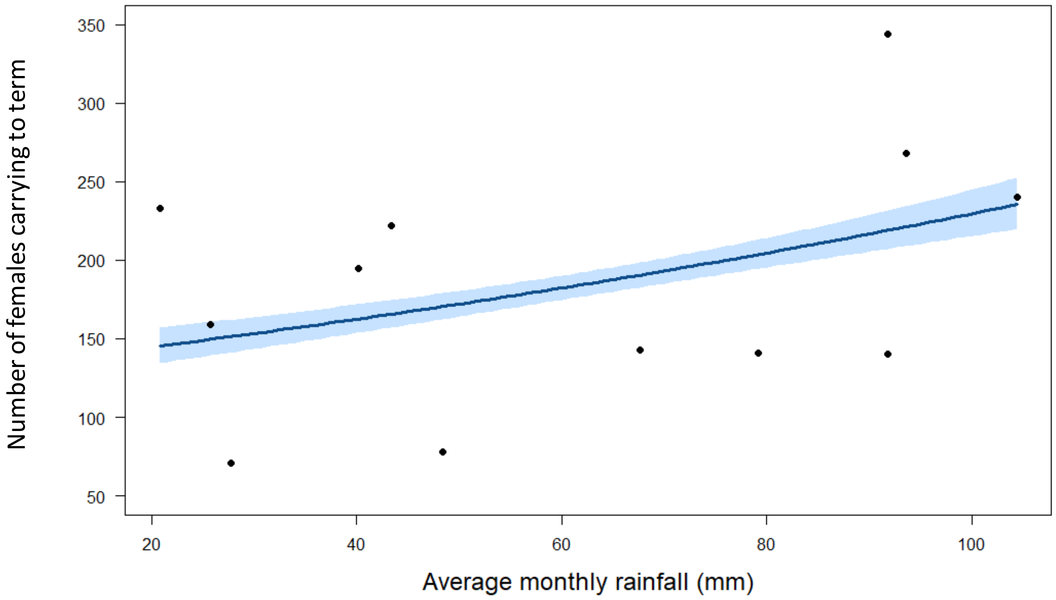

Figure 1: Response between the number of females carrying to term and the mean monthly rainfall across an average year. The shaded areas correspond to the 95% confidence limits.

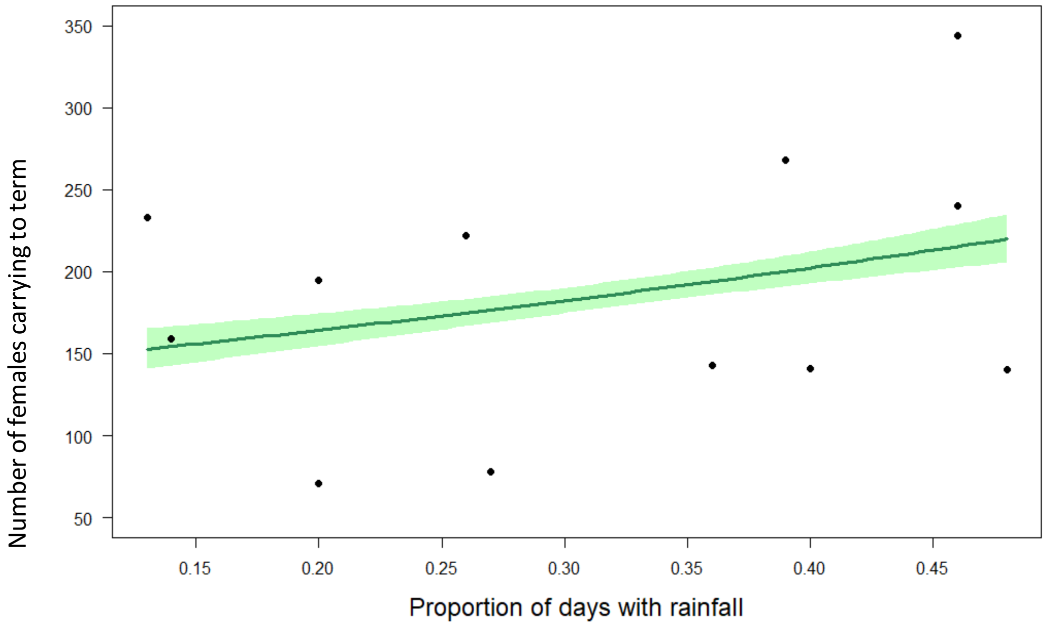

Figure 2: Response between the number of females carrying to term and the proportion of days with rainfall across an average year. The shaded areas correspond to the 95% confidence limits.

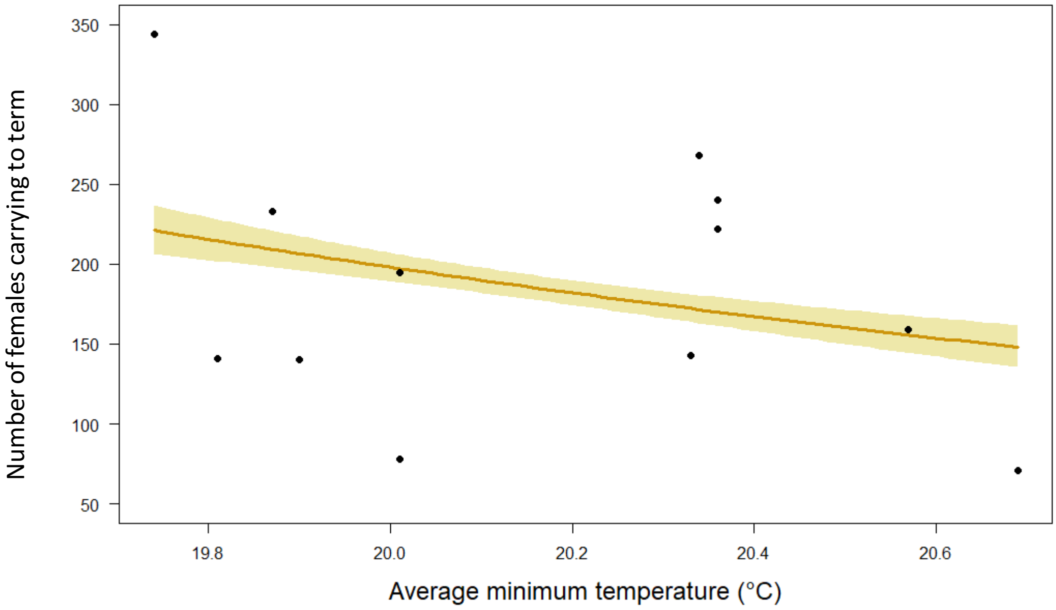

Figure 3: Response between the number of females carrying to term and the mean minimum temperature across an average year. The shaded areas correspond to the 95% confidence limits.

Appendix 1.2: Significant relationships for the number of pups produced across an average year

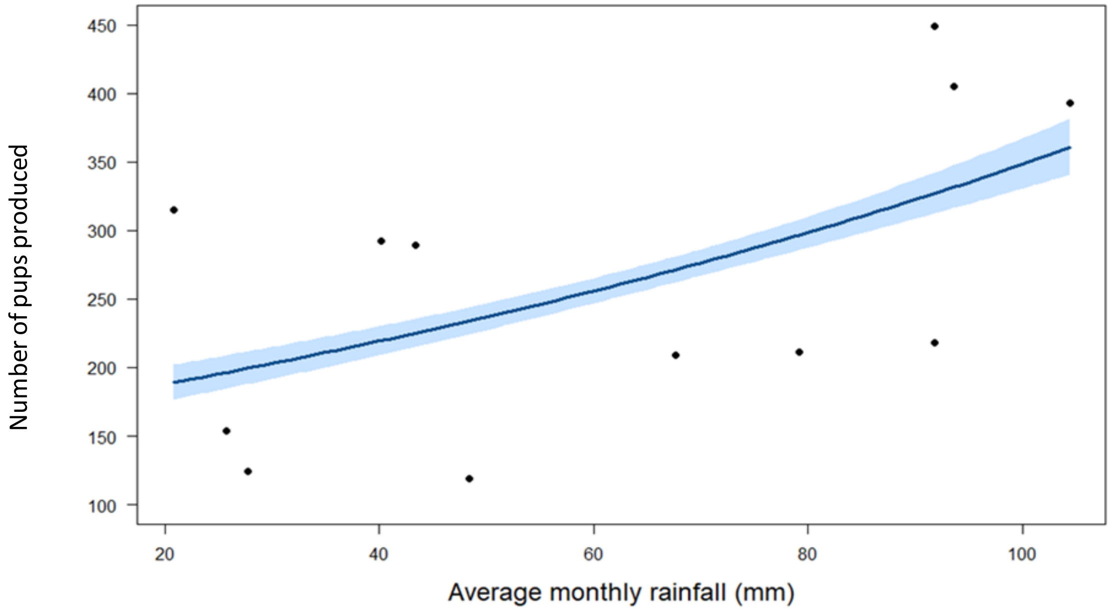

Figure 1: Response between the number of pups produced and the mean monthly rainfall across an average year. The shaded areas correspond to the 95%confidence limits.

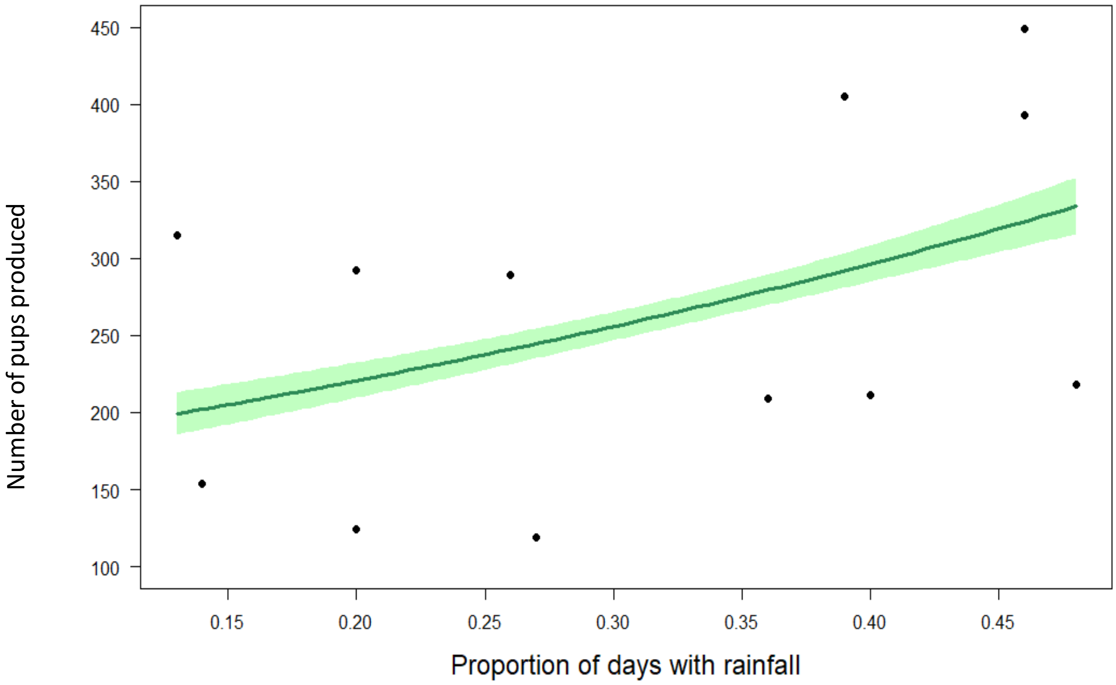

Figure 1: Response between the number of pups produced and the proportion of days with rainfall across an average year. The shaded areas correspond to the 95%confidence limits.

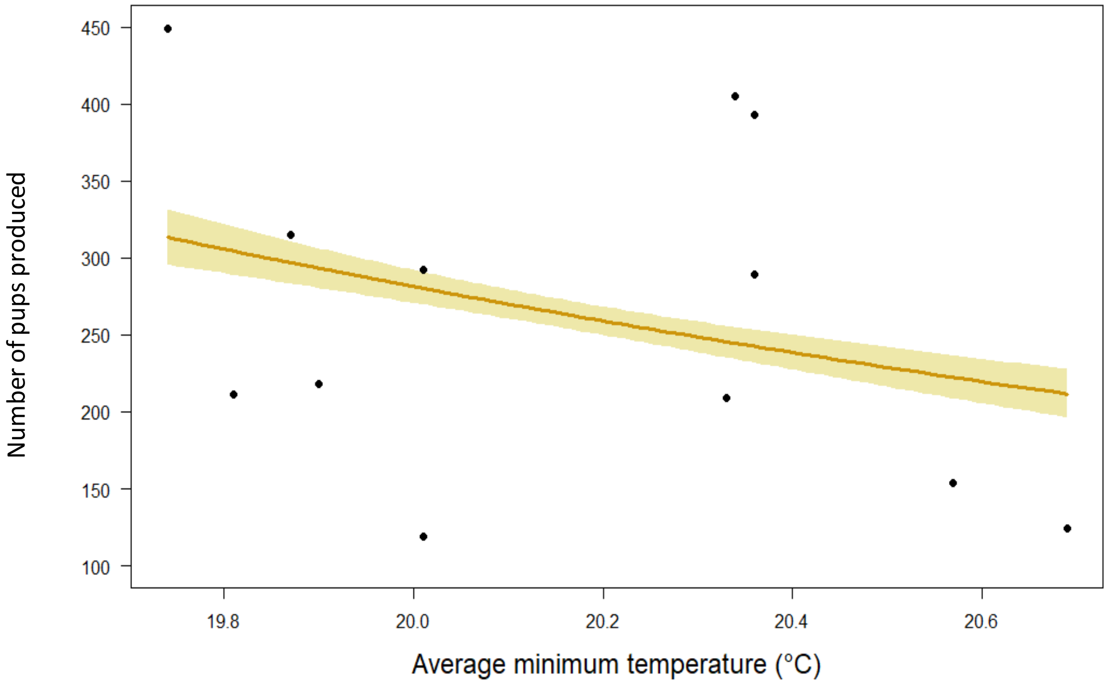

Figure 1: Response between the number of pups produced and the mean minimum temperature across an average year. The shaded areas correspond to the 95%confidence limits.

Appendix 1.3: Significant relationships for the number of pups produced across rainy seasons.

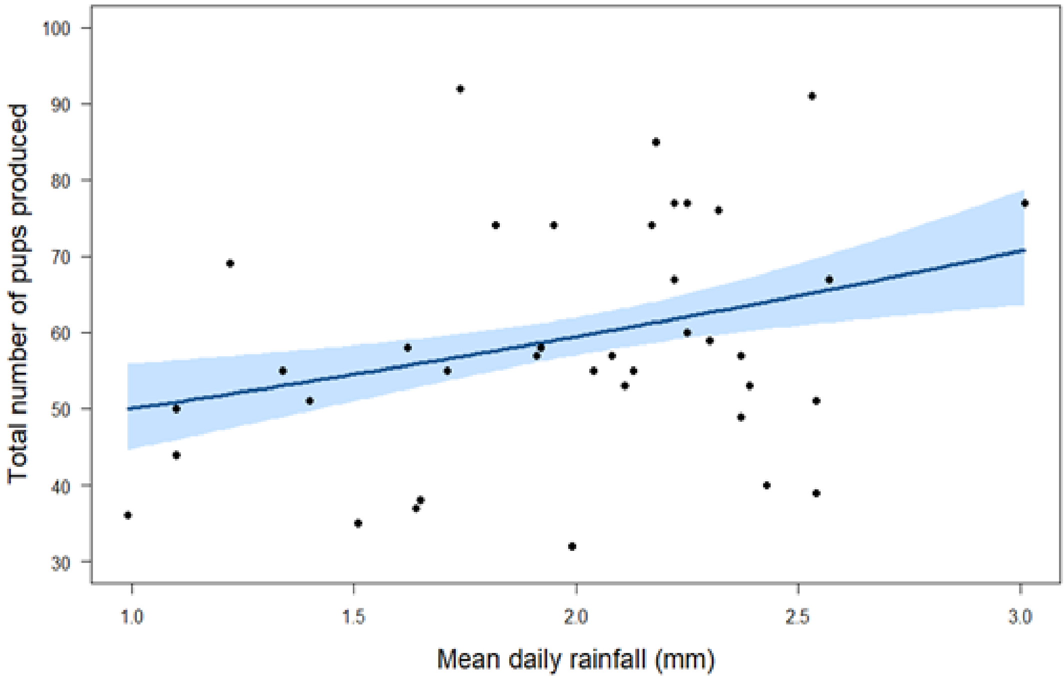

Figure 1: Response between the number of pups produced and the mean daily rainfall across rainy seasons. The shaded areas correspond to the 95%confidence limits

Appendix 1.4: Significant relationships for the proportion of pups surviving to independence across rainy seasons.

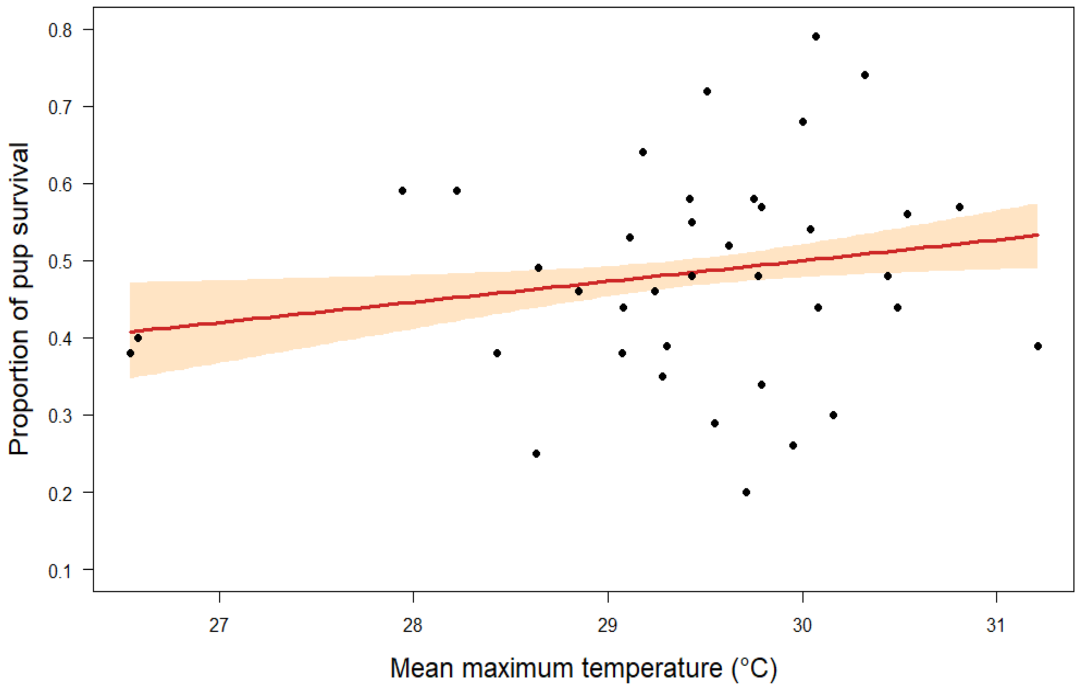

Figure 1: Response between the proportion of pups surviving to independence and the mean daily rainfall across rainy seasons. The shaded areas correspond to the 95%confidence limits

Appendix 2: Frequency of residuals and deviance residual of the fitted values for seasonal changes across a year for the number of females giving birth.

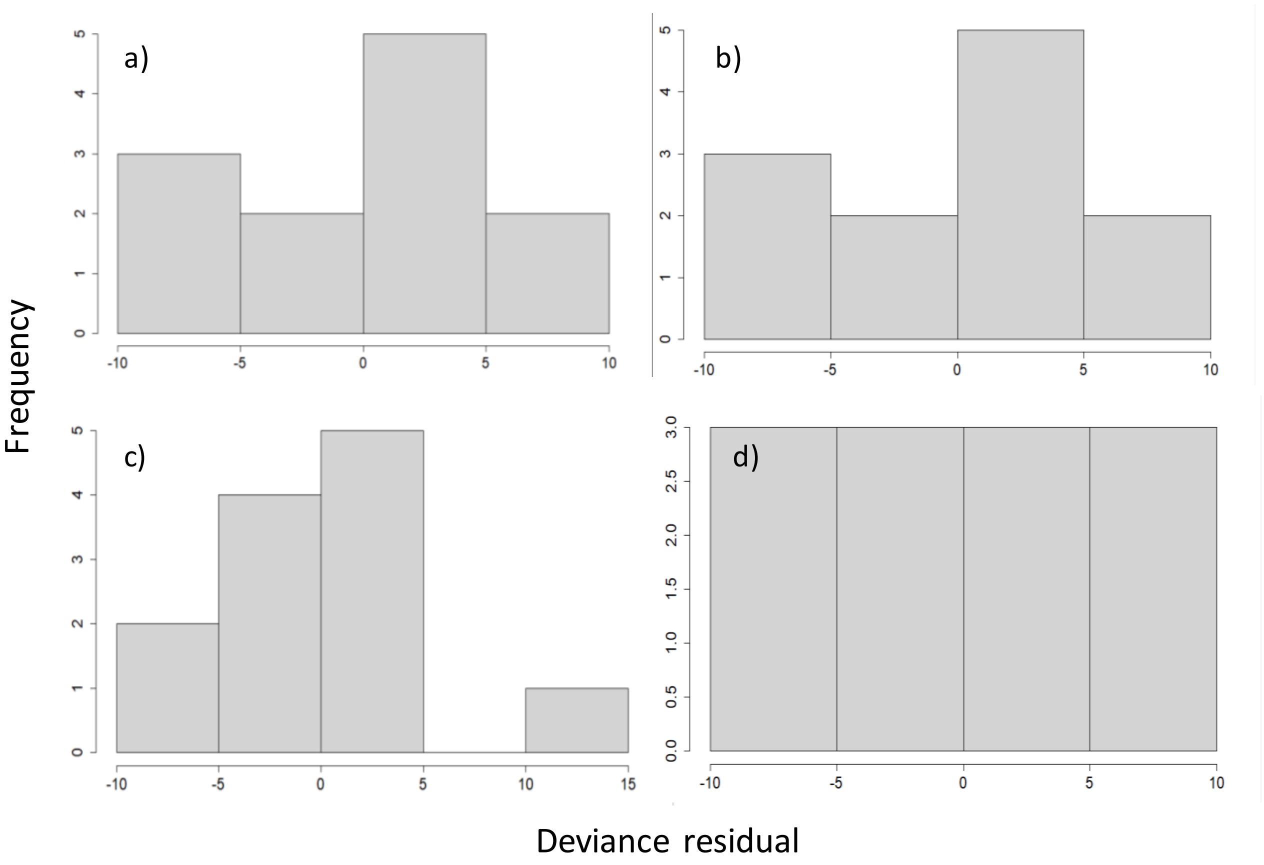

Figure 1: Frequency of residuals for the number of females giving birth to the a) mean monthly rainfall (mm), b) proportion of days with rainfall, c) mean maximum temperature and d) mean minimum temperature.

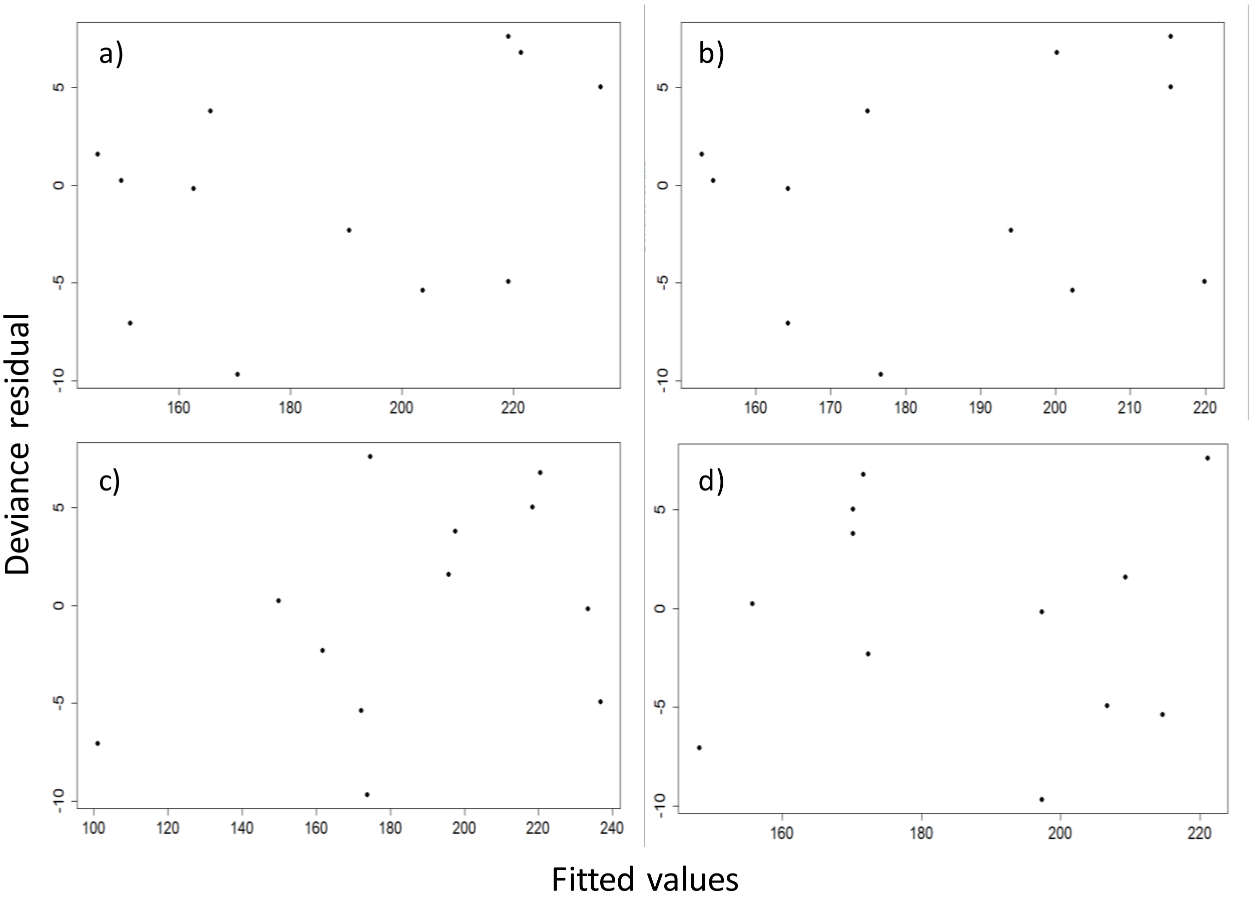

Figure 2: Deviance residuals of the fitted values for the number of females giving birth to the a) mean monthly rainfall (mm), b) proportion of days with rainfall, c) mean maximum temperature and d) mean minimum temperature.

Appendix 3: Frequency of residuals and deviance residual of the fitted values for seasonal changes across a year for the number of pups produced

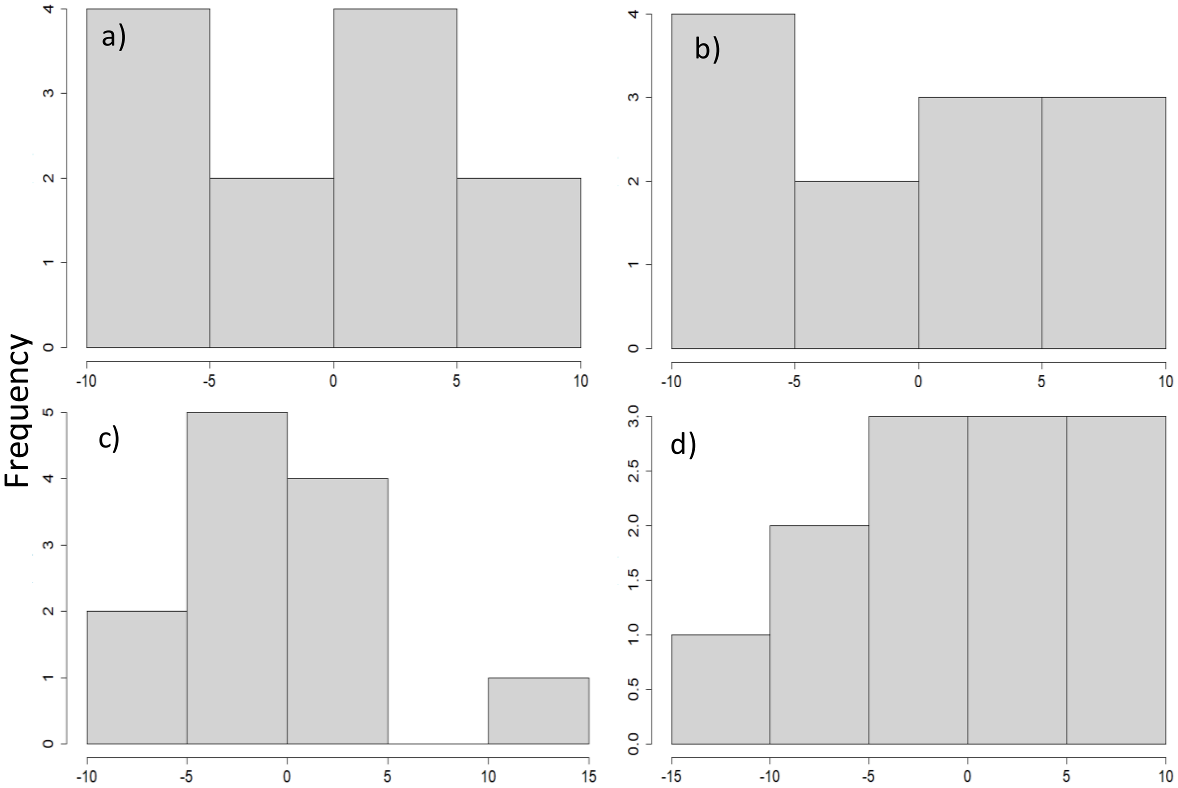

Figure 3: Frequency of residuals for the number of pups produced to the a) mean monthly rainfall (mm), b) proportion of days with rainfall, c) mean maximum temperature and d) mean minimum temperature.

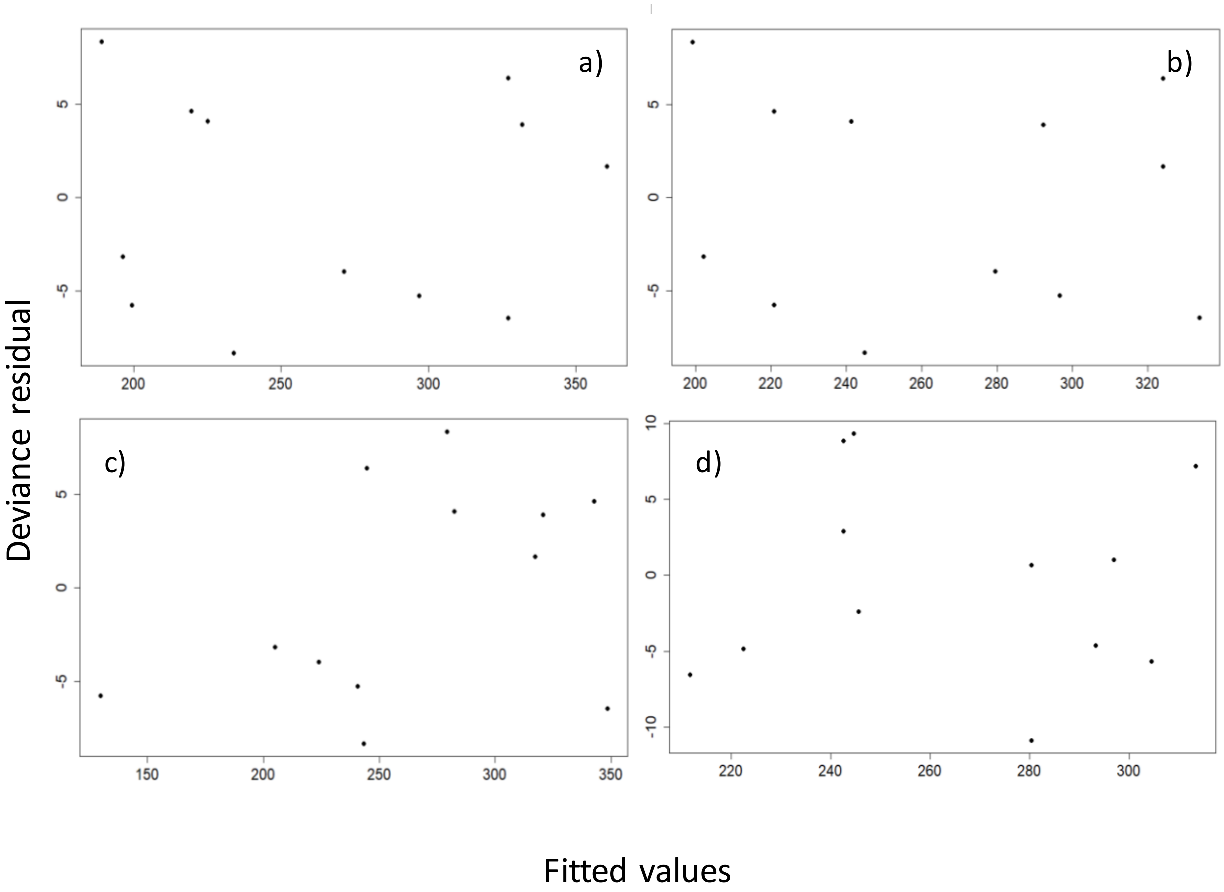

Figure 4: Deviance residuals of the fitted values for the number of pups produced to the a) mean monthly rainfall (mm), b) proportion of days with rainfall, c) mean maximum temperature and d) mean minimum temperature.

Appendix 4: Frequency of residuals and deviance residual of the fitted values for long term climate conditions across seasons for the number of females giving birth.

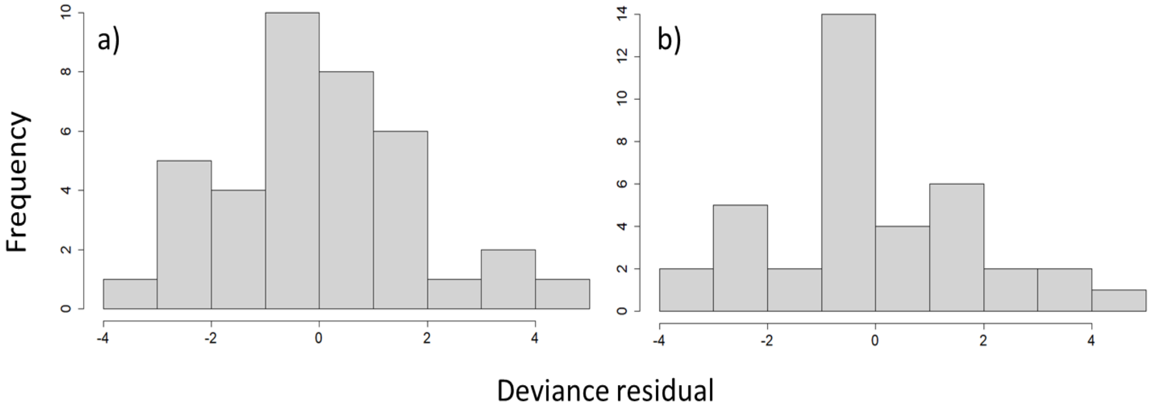

Figure 5: Frequency of residuals for the number of females giving birth to the a) combined daily rainfall and proportion of days with rainfall, b) mean maximum and minimum temperature.

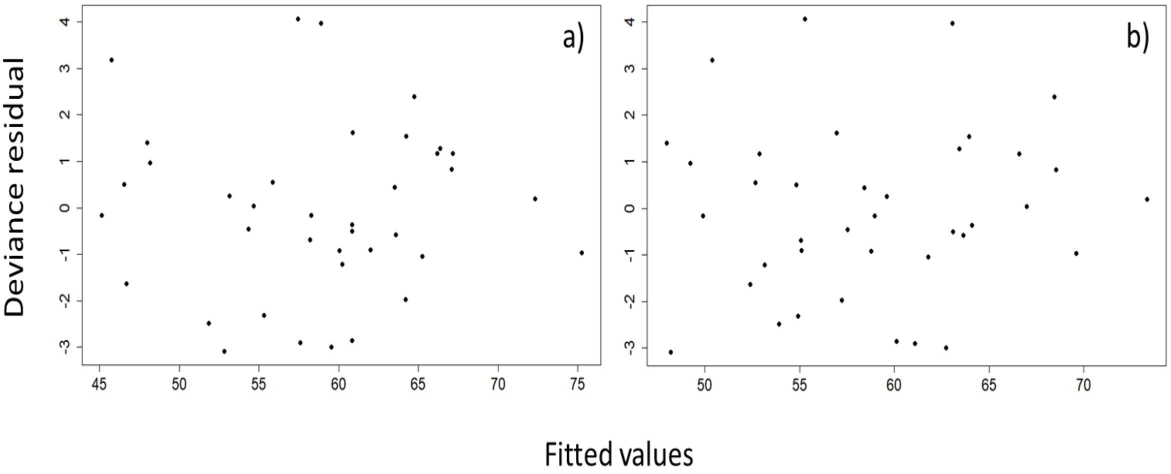

Figure 6: Deviance residuals of the fitted values for number of females giving birth to the a) combined daily rainfall and proportion of days with rainfall, b) mean maximum and minimum temperature.

Appendix 5: Frequency of residuals and deviance residual of the fitted values for long term climate conditions across seasons for the number of pups produced.

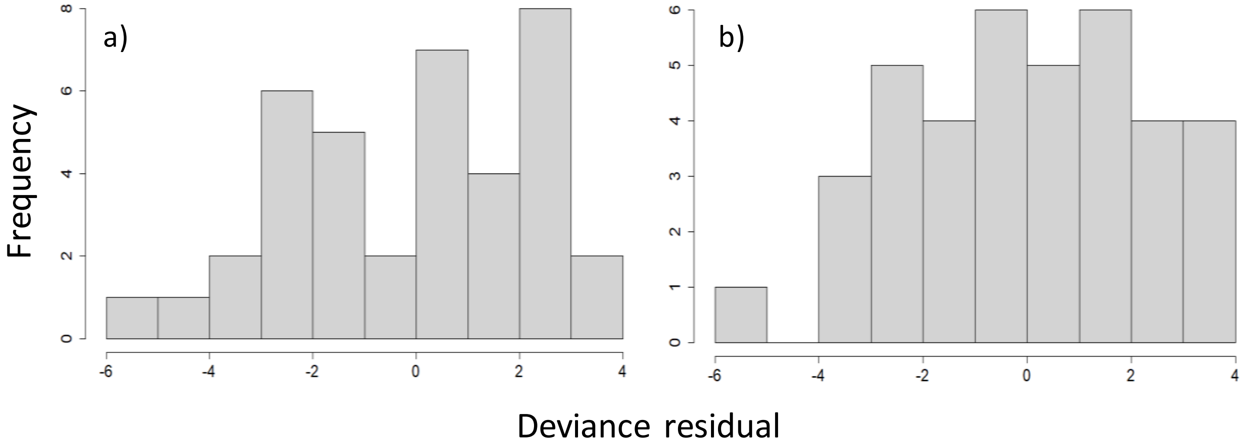

Figure 7: Frequency of residuals for the number of pups produced to the a) combined daily rainfall and proportion of days with rainfall, b) mean maximum and minimum temperature.

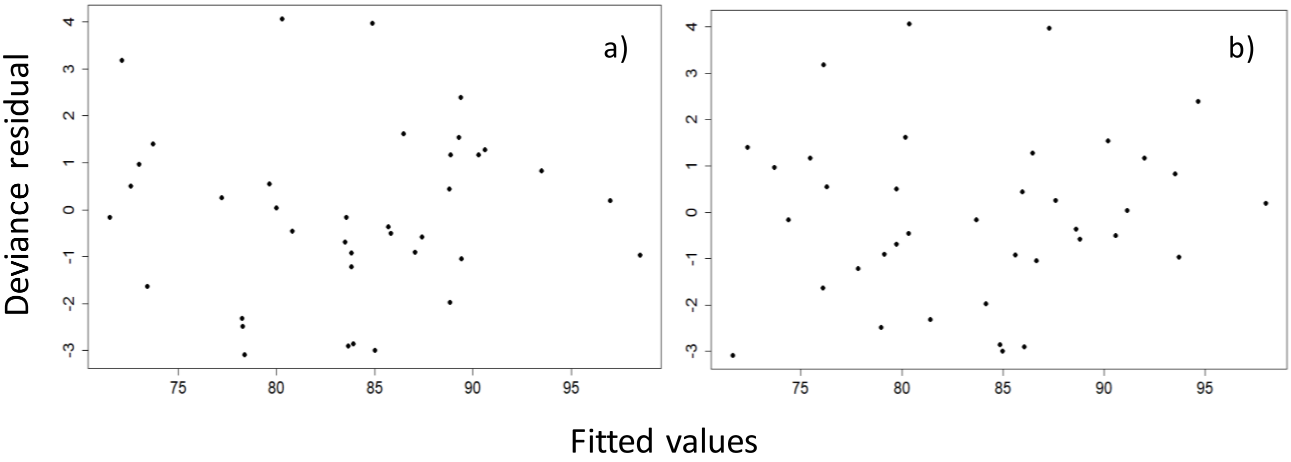

Figure 8: Deviance residuals of the fitted values for the number of pups produced to the a) combined daily rainfall and proportion of days with rainfall, b) mean maximum and minimum temperature.

Appendix 6: Frequency of residuals and deviance residual of the fitted values for long term climate conditions across seasons for the proportion of pups surviving to 90 days old.

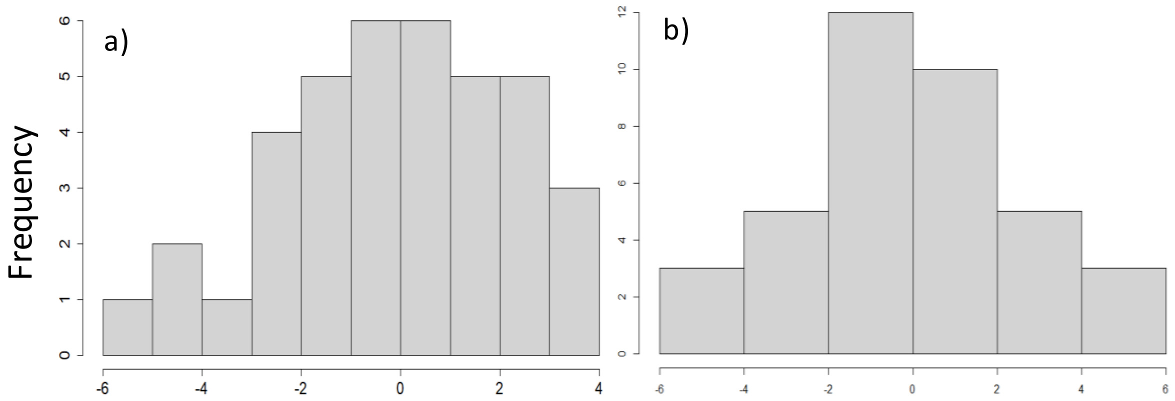

Figure 9: Frequency of residuals for the proportion of pups surviving to 90 days and the a) combined daily rainfall and proportion of days with rainfall, b) mean maximum and minimum temperature.

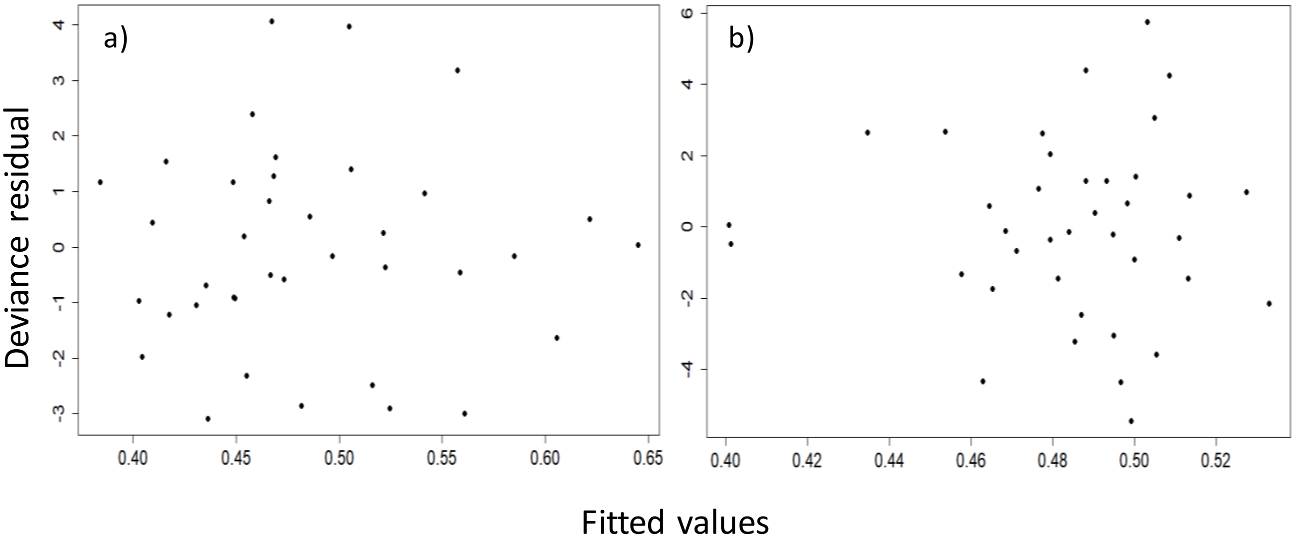

Figure 10: Deviance residuals of the fitted values for the proportion of pups surviving to 90 days old and the a) combined daily rainfall and proportion of days with rainfall, b) mean maximum and minimum temperature.

Appendix 7: Frequency of residuals and deviance residual of the fitted values for long term climate conditions across seasons for the proportion of litters emerging at 30 days.

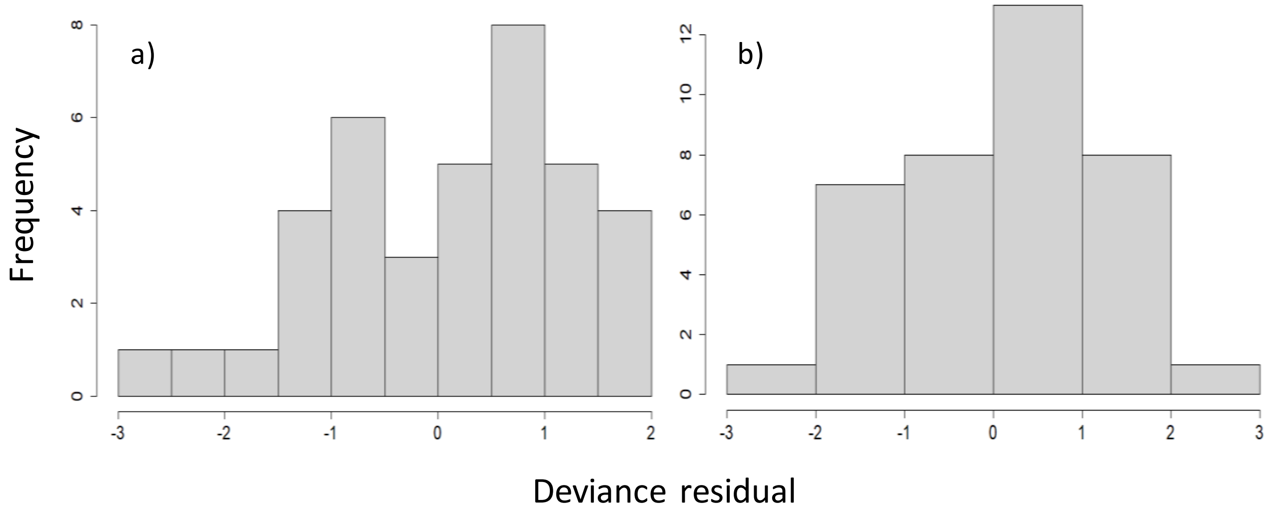

Figure 11: Frequency of residuals for the proportion of litters emerging after 30 days and the a) combined daily rainfall and proportion of days with rainfall, b) mean maximum and minimum temperature.

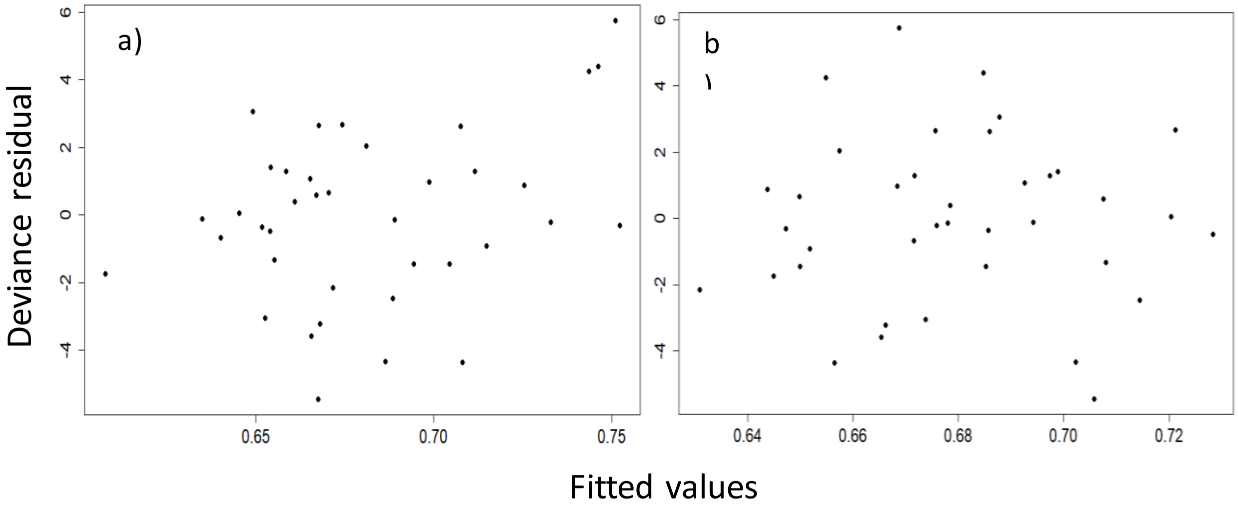

Figure 12: Deviance residuals for the fitted values for the proportion of litters emerging at 30 days old and to the a) combined daily rainfall and proportion of days with rainfall, b) mean maximum and minimum temperature.

Appendix 8: Frequency of residuals and deviance residual of the fitted values for long term climate conditions across seasons for the proportion of female pups being born into the population (sex ratio).

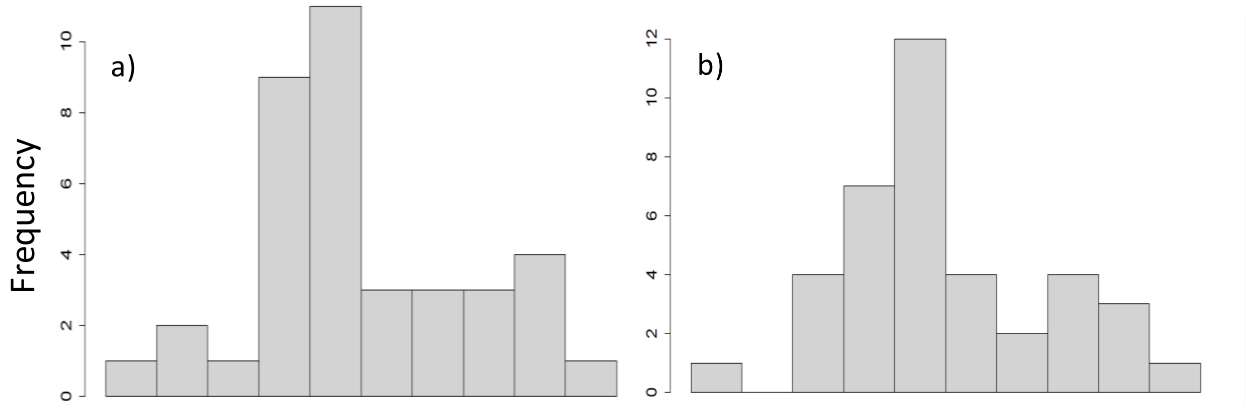

Figure 13: Frequency of residuals for the proportion of female pups being born over males to the a) combined daily rainfall and proportion of days with rainfall, b) mean maximum and minimum temperature.

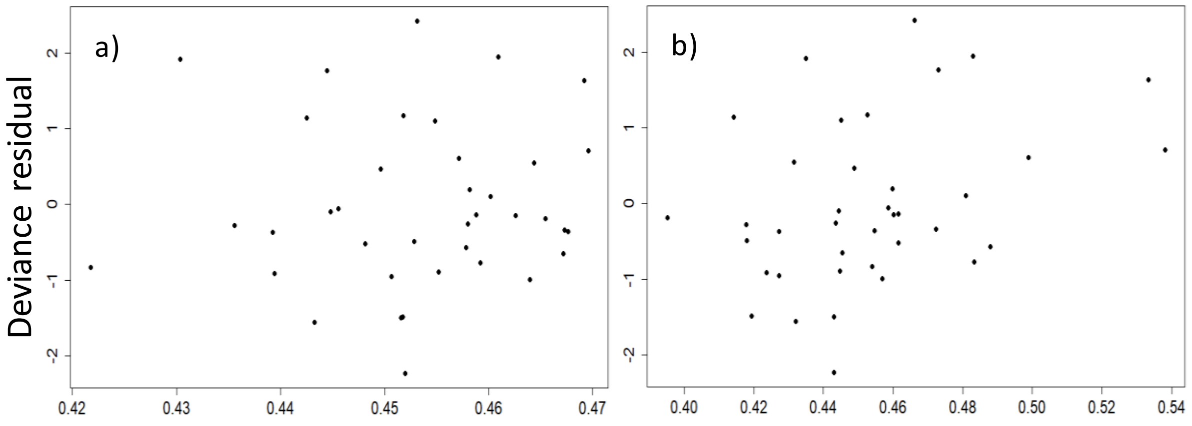

Figure 12: Deviance residuals for the fitted values for the proportion of female pups being born over males to the a) combined daily rainfall and proportion of days with rainfall, b) mean maximum and minimum temperature.

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