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Understanding the underlying factors of scent communication in the banded mongoose, *Mungos mungo*

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Abstract

Scent communication is the most widespread form of communication throughout the animal kingdom, whereby animals use semiochemicals such as pheromones to transfer information from one individual to another. Group living animals this method of communication to exchange an array information used to distinguish familiar individuals from competition, mark territories or identify potential mates. Banded mongooses, *Mungos mungo,* are an ideal model species to investigate the use of scent due to their cooperative breeding structure and prolific use of scent. Here we focus on a population of banded mongooses in Uganda that have a detailed record of individuals sex, ages, pregnancies and social groups. Using GC-MS to analyse the chemical profile of anal gland secretions from individuals alongside their life history we can identify potential factors that may influence an individual's chemical profile. Through general(ised) linear mixed effect models and analysis of similarities we were able to determine which factors might influence scent and how scent differs between demographics. We found that age has a significant influence on an individual's chemical profile as well as changes in chemical composition coinciding with seasons and reproductive status. Although there were no significant chemical differences between social groups, we did find that individuals produce chemically distinct scents that could be used in both inter and intra group communication. This research unveils the chemical foundations of scent communication within a social group living species.

Lay Summary

The use of chemicals to communicate is found across the living world from amoebas to mammals and can provide individuals with a wealth of information about their surroundings. Other mammals are particularly well adapted at using chemicals (perceived using scent), with many species able to recognise individuals, find mates and mark their territory boundaries. However, we know little about what chemicals are involved in scent communication. In this study we analyse the anal gland secretions of the banded mongoose to determine the number of compounds within each individual secretion. We found that individuals have distinct scents that are likely used in individual identification, but there were no such chemical signatures of group membership. Age heavily influenced the number and evenness of chemicals within the scent. We also found that temporal differences in scent composition and reproductive status also affected the number of chemicals in the profiles. Together, these results reveal the chemical patterns underlying scent communication in a social mammal.

Key words: Chemical communication, Banded mongoose, *Mungos mungo,* Scent, Gland, GC-MS

Abbreviations: Anal gland secretions (AGS), generalised linear mixed effect model (GLMM), linear mixed effect model (LMM), gas chromatography – mass spectrometry (GC-MS

Declarations

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed: [redacted]

Date: 24/09/2025

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

Signed: [redacted]

Date: 24/09/2025

I hereby give consent for my thesis, if accepted, to be available for electronic sharing

Signed: [redacted]

Date: 24/09/2025

The University's ethical procedures have been followed and, where appropriate, that ethical approval has been granted.

Signed: [redacted]

Date: 24/09/2025

Statement of Expenditure

Student name: Lucie Murphy

Student ID: 2104977

Category	Item	Description	Cost
Software	Primer 7 + PERMANOVA Student license	Community analysis software for diversity analysis	£342.14

Statement of Contributions

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Contributor Role	**Persons Involved**
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Data Curation	HN, LM, BC, FM, MC
Formal Analysis	LM, HN, BC
Funding Acquisition	HN, MC
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Project Administration	HN, FM, MC
Resources	HN, JH
Software	LM
Supervision	HN, BC
Validation	LM, HN, BC
Visualization	LM
Writing – Original Draft Preparation	LM
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Introduction

Communication is crucial for all animal species as it allows the transfer of information from one individual to another as well as the internal cell to cell communication within organisms. Communication depends on the presence of a signaller producing a signal with the intent of eliciting a response from a receiver (Searcy et al., 2005). These interactions can occur on a micro scale with inter-cellular communication mediating internal reactions and organism development to much larger intergroup communication (Witzany, 2018). Signals used to communicate can utilise many senses including auditory, visual and electromagnetic however the universal and oldest form of information transfer is chemical.

Infochemcials are the biological molecules that are used to disseminate information, encompassing both hormones for internal chemical communication and semiochemicals responsible for the chemical communication between organisms through olfactory means(Müller et al., 2020). It is these semiochemcicals that are used by individuals to gain information about potential mates, competition and food (Happ, 1973; Naguib and Price, 2013). There are two key types of semiochemical: pheromones and signature mixes. Pheromones are released with the intention of eliciting a specific innate response in the receiver and are involved during intra-specific communication (Wyatt, 2014). They are structurally very diverse, varying in size from small peptides to larger g-protein ligand complexes which can be combined in precise ratios that are secreted through faeces, urine, saliva or specialised glands (Brennan, 2010; Liberles, 2014; Wyatt, 2017). Pheromones secreted by individuals are inherited and the responses to them are innate. In contrast, signature mixtures are used to identify individuals (Wyatt, 2010). This subset of molecules is learned through exposure to distinguish scents from others enabling recognition of conspecifics or social groups (Roberts et al., 2018).

Since the initial recognition of pheromones and the first molecular structure being recorded over 60 years ago, the research surrounding scent communication has developed (Butenandt et al., 1959; Karlson and Lüscher, 1959). The use chemical communication has since been identified in both aquatic and terrestrial environments spanning across vertebrate and invertebrate species (Brönmark and Hansson, 2000). Mammals are especially dependant on olfaction with many non-human mammals possessing over 1000 olfactory receptors and the specialised Jacobson organ, debated to be present in humans, allowing species to detect a range of scents far greater than humans are able to (Niimura, 2012; Stoyanov et al., 2018).

New techniques have allowed for in depth investigation into the contents of animal scent marks. Modern methods such as gel electrophoresis or liquid and gas chromatography coupled with mass spectrometry (G/LC-MS) have frequently been used to study the identity and diversity of volatile organic compounds within animal secretions (Soso et al., 2014). Regardless of the type of G/L-MS technique the number of compounds within samples is based on the time taken for compounds to travel through the chromatograms capillary column as each chemical has a different retention time depending on polarity and molecular weight. The main difference between the techniques involving chromatography and mass spectrometry is the volatility of the compounds being analysed. Headspace GC-MS is best suited to analyse highly volatile organic compounds as sampling is isolated to the air space above secretions (the headspace) ,whereas LC-MS provides insight into the less volatile compounds. GC-MS can identify some highly volatile and less volatile compounds from liquid samples.

Using these new techniques our knowledge on chemical communication has advanced beyond purely observational by allowing for detailed and quantitative analysis of chemical communication in species (Ranjan et al., 2023). Despite these new developments in studies on scent communication in animals there has primarily been a focus on invertebrate species whereas our current knowledge on scent communication in vertebrates, and mammals in particular, is based on behavioural observations with few studies now incorporating these new techniques (Campbell-Palmer and Rosell, 2011).

Through research on both wild and captive mammals we can understand that scent aids in the maintenance of social dynamics such as mate attraction and kin recognition (Baum and Keverne, 2002; Keller et al., 2010). For example, many lab based studies on rodents have confirmed that scent is used to communicate intersexually with exposure to urinary scents inducing early sexual maturation in males and oestrus in females (Wölfl et al., 2023; Garratt et al., 2024). The use of scent is also highly important for territorial species. Canid species are particularly well studied in the use of scent to signal to competitors, maintain territory and overmark females to retain mates (Biswas et al., 2025). The recognition of group members and individuals through scent is another key function of chemical signals that enable infant recognition by mothers, mate choice and attraction as well as aiding in inbreeding avoidance (Brennan and Kendrick, 2006). Recent work focusing on male dingoes, *Canis lupus dingo,* found using headspace GC-MS that a male's age can be encoded in urine samples (Walker et al., 2024). Similarly work on meerkat, *Suricata suricatta,* anal gland secretions found that the chemical composition and microbiome community was different depending on group membership, dominance, and age (Leclaire et al., 2017). Finer distinctions can also be detected in the chemical profiles. African elephants, *Loxodonta Africana,* are one species that are able to identify individuals from temporal, buccal and genital odours (von Dürckheim et al., 2022). Seasonal differences could also influence chemical communication and in many species there are seasonal changes that coincide with breeding seasons. Early work on meadow voles, *Microtus pennsylvanicus,* suggests the observable effects of scent coincide with changes in photoperiods (Ferkin et al., 1995). Similar effects have also been seen in giant pandas, *Ailuropoda melanoleuca*, as individuals alter behaviours in response to scents throughout the year with less intense marking and investigation during the winter compared to summer months (Hou et al., 2021).

The banded mongoose, *Mugos mungo* is an excellent species to study scent communication due to their group living dynamics and prolific scent marking behaviour observed. Banded mongooses are small (~1.5kg) diurnal group living mammal that reside in groups of up to 75 individuals (Cant et al., 2013). They engage in cooperative breeding within their large mixed sex groups, with females regularly having synchronous births and the resulting offspring being cared for by multiple group members including non-breeders (Hodge et al., 2011). During times when in oestrus males will aggressively mate guard females for the opportunity to mate and while individuals typically remain within their natal clan there is low inbreeding within groups (Sanderson et al., 2015b). This inbreeding avoidance is achieved by males seemingly mate guarding unrelated females within the clan to gain paternity which is energetically expensive, alongside females controlling paternity with successful breeding typically occurring with unrelated males (Nichols et al., 2010; Sanderson et al., 2015b). This small African mammal is also highly territorial and will frequently engage in intergroup conflicts sometimes resulting in serious injury (Cant et al., 2002; Nichols et al., 2015). These intergroup interactions are more frequent during dry periods especially within larger groups which coincides with the desire for more resource control and territory. Not only are these conflicts related to obtaining more resources but also to have access to more mates with many interactions occurring during oestrus (Thompson et al., 2017).

Studying our population for over 30 years has led to a deep understanding of the group dynamics, mating behaviours and intergroup interactions of these animals. This has allowed us to collect information on multiple individuals throughout their life as well as observe behavioural responses to scent and collect samples due to habituation. Having such in depth information allows for thorough research in both observational and chemical studies in order to understand the underlying mechanisms of banded mongoose scent communication. Previous work investigating banded mongooses use of scent has heavily relied on behavioural observations, with the use of scent presentations and in-field surveys. Territory marking using scent has been observed between groups, with scent markings occurring in much higher densities in overlapping areas at the edge of territories compared to areas exclusive to individual groups (Jordan et al., 2010), suggesting that odour may be important in advertising territorial ownership. Banded mongooses also recognise familiar individuals through exposure to conspecifics unique scents as different responses were observed when individuals were presented with scents from familiar and unfamiliar individuals (Mitchell et al., 2018). This ability to recognise individuals through scent could indicate that discrimination of non-group individuals could be due to learning scents. Alternatively, the discrimination between mongooses that are within or outside of an individual’s group could be due to a distinct group signature like the group-specific scent pouch microbiomes found in spotted hyena, *Crocuta Crocuta* (Theis et al., 2012) .

Perhaps the most well studied factor in relation to scent communication is sex. Both Male and female banded mongooses have been recorded to overmark more on same sex markings than on markings from the opposite sex within their own social group

(Jordan et al., 2011a; Jordan et al., 2011b; Jordan et al., 2011c). Not only do males overmark other males scent markings but do so at a higher frequency around non-pregnant females as a form of mate guarding (Mitchell et al., 2017). This preference to overmark same sex markings could be a form of intrasexual competition within both sexes to obtain reproductive dominance over other group members (Jordan et al., 2011a). This ability to detect sex through scent transcends across groups with individuals identifying the sex of unfamiliar animals from scent presentations with unfamiliar female scent inducing a more intense response than familiar scents (Mitchell, 2017). In accordance with this, differences between sexes have also been observed through GC-MS analysis of anal gland secretions (AGS) (Jordan et al., 2011a). Similarly, sex differences have also been observed across other species within the family Herpestidae with early research on Egyptian mongooses*, Herpestes ichneumon,* recognising sex specific carboxylic acids within AGS (Hefetz et al., 1984).

One factor that could influence banded mongoose scent communication but is yet to be thoroughly investigated is the influence of age. While age can often be inferred from the ranked age which is used frequently based off early work with the Ugandan population, the direct relationship between age and chemical composition of signals is still understudied (Brönmark and Hansson, 2000; Cant, 2000; Nichols et al., 2012) . Observations of overmarking behaviour has found that older individuals overmark more frequently than younger individuals (Jordan et al., 2011a). In meerkats there has been some investigation into the changes of microbiome in anal scent secretions finding that differentiation occurs after individuals become sexually mature (Leclaire et al., 2014). This suggests that age could influence scent communication especially when individuals reach sexual maturity.

Whilst extensive observational behaviour studies have revealed differences in behavioural responses to odours from conspecifics, there are very few studies that have attempted to investigate the chemicals involved in scent communication in this species (aside from assessing sex-differences and individual consistency in chemical profiles). Here, we use GC-MS to investigate the factors underlying chemical diversity and similarity of banded mongoose AGS. Specifically, we investigate the influence of age, sex, group membership, seasonality and reproductive status on the chemical diversity and similarity of AGS. Based on previous scent presentation studies in banded mongooses we expect to find significant chemical differences between the sexes and an influence of female reproductive status on the chemical composition of AGS, which may be associated with the season. If age is chemically encoded, rather than learned, we expect to find differences in the chemical profiles associated with age. Finally, we also expect to find evidence of individual signature mixes, and potentially also signature mixes reflecting social group membership.

Methods and materials

This study uses samples collected from individuals that inhabit Mweya Peninsula in Queen Elizabeth National Park, Uganda (central point: 0˚11.5'S, 29˚54.0'E). This population of banded mongooses (consisting of approximately 200 individuals alive at any one time) has been continuously studied since 1995, providing over 30 years of information on the life history and behaviour of over 3000 individuals, (Cant, 2000; Marshall et al., 2018). Here, we sampled anal gland secretion from 154 individuals between 23/11/2018 – 15/4/2019, which included two wet seasons between March – May and September – November and one dry season between December – February.

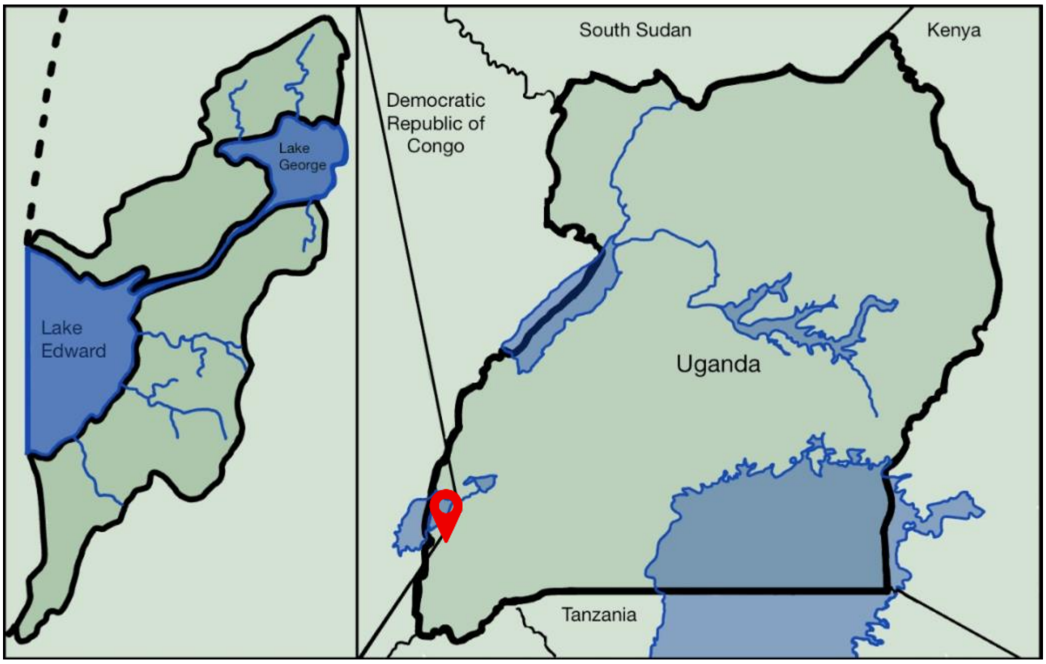

Figure 1. Simple illustration of Queen Elizabeth National Park map (left) and its location in Uganda (right)

Sample collection

Odour samples were collected by Dr David Wells, Mr Francis Mwanguha and their field assistants. All samples were collected under anaesthetic following the procedures outlined by Mitchell (2017). In brief, the anal area was first cleaned and with cotton wool and vial placed over the exterior an anal gland located each side of the anus. The examiner then applied pressure to the anal gland to extract the secretion until approximately ~150µL from each gland was collected into the same glass chromatography vial (Fisher scientific) and sealed with polytetrafluoroethylene (PTFE) – faced screw cap lid. To avoid contamination, vials were pre-cleaned with methanol and then pentane with air drying between each solvent, gloves were changed between individual mongooses and examiners fingers never came into contact with secretion or top of vials. Six control samples were also taken, which comprised of empty vials that had been opened and closed again at the field site. These samples were taken to indicate any chemical contamination resulting from the processing of samples in the field. Samples were labelled and stored in the field in a dewar of liquid nitrogen. To maintain integrity of samples during transit to Bielefeld University, Germany (where chemical analysis was conducted), samples were placed on dry ice and then stored in a -80˚C freezer upon arrival.

GC-MS protocol

Sample preparation was conducted by Dr Hazel Nichols at Bielefeld University between November 2019 and January 2020. After defrosting at room temperature, samples were centrifuged at 4000rpm for 1 minute to draw samples to the bottom of the vial and then vortexed for 10 seconds to mix them. Following this, 10µL of the sample was added to 190µL of dichloromethane in a clean glass vial using a pipette and tip that were pre-cleaned in dichloromethane. This allows the volatile and non-volatile compounds within secretions to be dissolved into a volatile solvent enabling evaporation which is required.

In some cases, due to inconsistencies in sample viscosity or a low amount of anal gland secretion obtained from the mongoose, less than 10µL of sample was available for analysis. In this case, the volume of dichloromethane was reduced accordingly to maintain an approximate ratio of sample to dichloromethane of 1:19 with the minimum volume of dichloromethane used being 50µL. Samples were then stored at

-80˚C prior to chemical analysis.

Samples were then analysed using gas chromatography coupled with mass spectrometry GC-MS by Dr Hazel Nichols and Prof Barbara Caspars. Samples were defrosted and 40µL of the sample-dichloromethane mix was added to a glass GC-MS insert using a glass pipette (both pre-cleaned with dichloromethane) and held inside a larger glass vial labelled with the sample identity.

Samples were run on a GC-MS machine model GC2030-QP2020NX (Shimadzu) with the VF-5ms capillary column (30 m × 0.25 mm ID, DF 0.25, 10 m guard column, Varian Inc. Lake Forest, USA). In this analysis we used helium as the carrier gas at 1ml/min flow rate. GC temperature was 60 ˚C for 3 minutes then increased by 10˚C/min until 280 ˚C which was maintained for 20 minutes. Here the compounds travel through the column at different speeds resulting in different retention times. After chromatography the compounds enter the mass spectrometer whereby high impact ionisation break the compounds resulting in the recording of the mass spectrum to be used in identification (Walker and Vaglio, 2021). There was a total of 253 samples, 6 controls. An additional 37 blank samples (containing only dichloromethane) were included in the GC-MS run at approximately even intervals to clean the machine and indicate potential chemical contamination.

Life History Data

Information on the life history of individuals was collected by the research team from the Banded Mongoose Research Project based in the Queen Elizabeth National Park. For visual identification mongooses were fitted with colour coded colours, dye patterns in fur or shaved fur patterns (Schubert et al., 2025). Individuals are also recognised by the tattoo or subcutaneous pit tags that were given while under anaesthetic during first capture (Cant, 2000; Schubert et al., 2025). Within each social group, there were one or two individuals fitted with radio collars with 20cm antenna. Observations of groups occurred every 1-3 days to record the presence or absence of individuals, and any signs of pregnant females or new births. Birth dates (and hence age data) were inferred through observing changes in body shape of previously pregnant females, along with observing the onset of pup care.

We used dates of birth to determine the reproductive status of females. Gestation takes on average 62 days therefore if a female gave birth within 62 days of an AGS sample being taken, it was assumed that the female was pregnant. Dates of birth were also used to deduce when females were likely in oestrus. With oestrus lasting on average 6 days, we can assume that the period between 68 and 63 days before birth females were likely in oestrus. The group reproductive period was also included to test if there were changes in conspecifics' chemical composition when females are in oestrus or pregnant as this may correspond to the changes observed in overmarking behaviours. To account for this, we based group reproductive period on female reproductive status therefore if at least one female was pregnant or in oestrus the group reproductive period was oestrus or pregnant.

Alignment of Chromatograms

All processing of chromatograms and downstream statistical analyses were conducted by Lucie Murphy at Swansea University. The retention times and peak areas were extracted from the GC-MS chromatograms and were then aligned to compare the chemical composition which was done using the GCalignR package (Ottensmann et al., 2018) in R version 4.2.1 (R core team, 2022).This package allows us to conduct the steps needed to match peaks from homologous substances within samples. With chemicals having different retention times across samples, we must first account for any minor shifts in the retention time by shifting samples towards a reference sample. This is done by setting the max linear shift to 0.05 which is the maximum time the whole sample can be shifted which would be 3 seconds. The GCalignR package alignment process aligns peaks across samples, comparing each individual peaks' retention time with the mean retention time of that peak across all samples. This is controlled by the maximum difference between peaks and maximum difference between a peak and the mean retention time for that compound. If retention time falls within the range set it joins that row, if it falls outside it will join the next row. The final step of alignment resolves the issue that homologous peaks might get sorted into separate rows in the previous step and is achieved using the minimum peak difference that will prevent peaks closer than the threshold to be considered as separate compounds. Here we set the minimum peak difference to 0.05 as for most of our samples the difference between peaks is greater than 0.05 (figure 2) (Ottensmann et al., 2018).

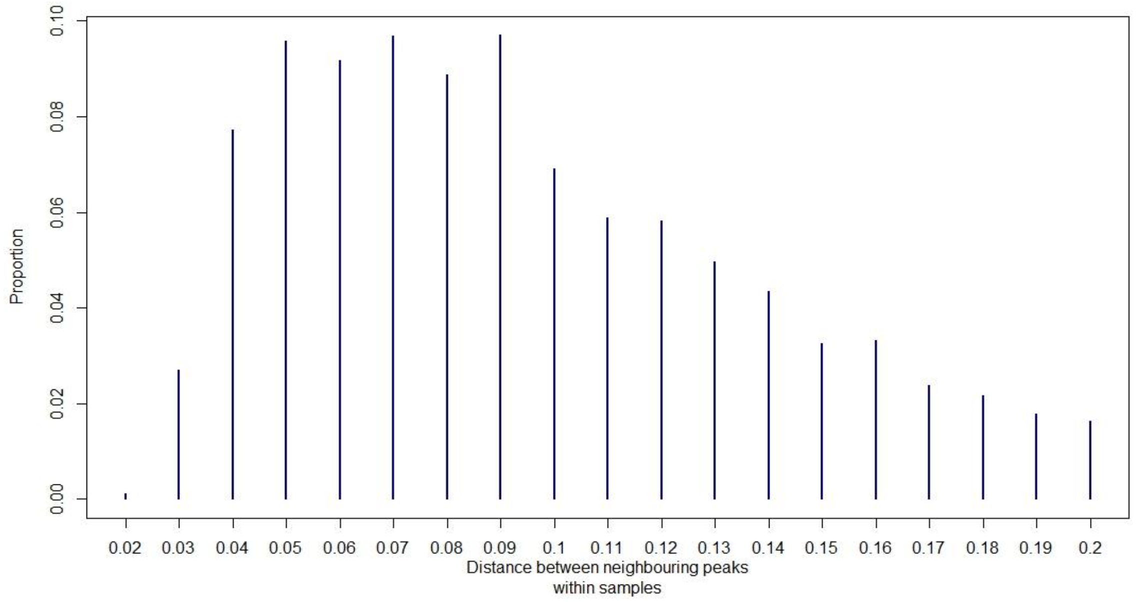

Figure 2. Histogram showing the distribution of the spaces between retention time (minutes) for peaks in chromatograms

An initial alignment included all samples, controls and blanks. Controls contained very few peaks compared to samples (Figure 3), suggesting very little contamination resulting from field collection procedures, so controls were therefore emitted from further alignments. Blanks also contained substantially fewer peaks compared to samples (Figure 3). Whilst some studies remove all peaks found in blank samples, this may lead to the omission of biologically relevant chemicals if there has been a small amount of contamination resulting from the analytical procedure. Instead, we retained all peaks in our analyses and did not include blanks in future alignments.

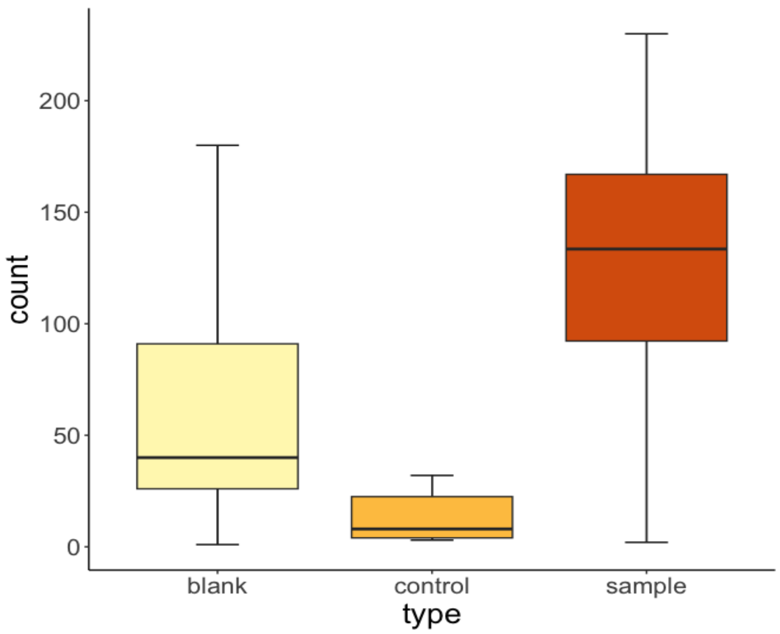

Figure 3. Number of peaks within chromatograms from samples, blanks and controls. Median of each sample type represented with thick black line within box and whiskers represent the range 1.5 x IQR outside of 2nd and 3rd quartiles

After removing control and blank samples, further cleaning of the chemical data involved the removal of 9 samples from 7 different individuals that were incorrectly labelled or had no life history records. Using the cleaned output multiple alignments were conducted using different samples as reference to determine which sample is most suitable reference sample. To recognise the best sample to be used for further analysis we visualised alignments using heatmaps which present the presence or absence of a substance within a sample. We used the heatmap function in GCalignR to determine the best alignment based on the distinction of clear bands being visible for substances (figure 4). For our final alignment we used sample 24F017_150419 as reference, a minimum difference between peaks set to 0.05, cut off time before 3 minutes and after 45 minutes, maximum distance of peak to mean set to 0.03, deletion of peaks found in only one sample and the maximum shift for linear corrections set to 0.05. The alignment was transformed by logx + 1 prior to statistical analysis to standardise the concentrations of substances and in preparation for Bray-Curtis resemblance analysis.

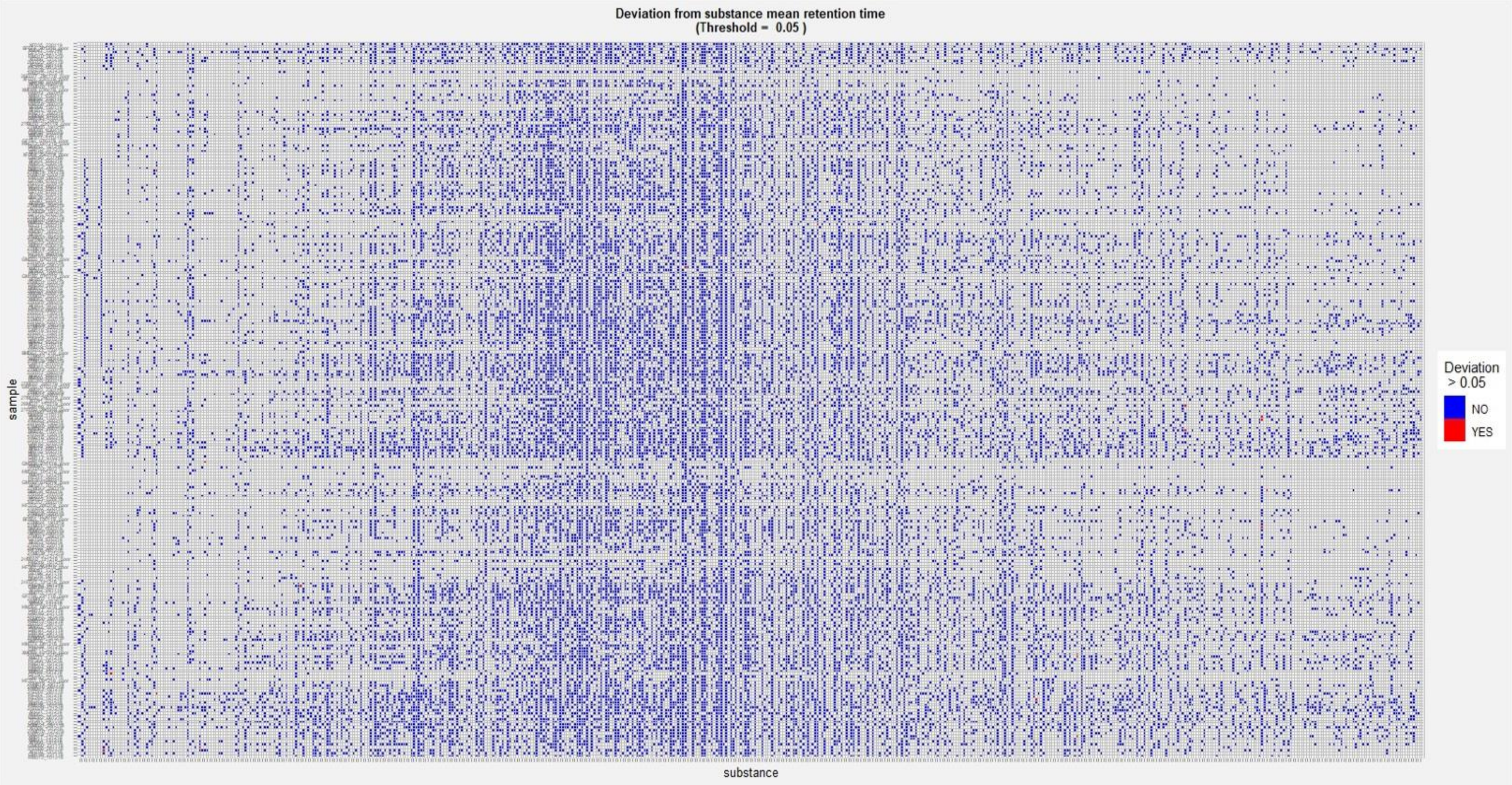

Figure 4. Final alignment of sample chromatograms where each row represents one samples chromatogram and columns represent substances. Threshold for deviation of individual peak times from the mean retention time of respected substance was set to 0.05 if a retention time exceeded this deviation threshold it is highlighted in red and if the retention time deviated less than 0.05 it is highlighted in blue.

Chemical Similarity

Aligned chromatograms were analysed in Primer7 (version 7.0.23, PRIMER-e, https://www.primer-e.com/software). First, a Bray-Curtis similarity matrix between all samples was produced which calculates the similarity of each sample against all other samples. We then conducted analyses of similarities (ANOSIM) each with 999 permutations. This non-parametric statistical test compares the differences within groups to differences between groups based on distances within the Bray-Curtis similarity matrix. We first conducted an ANOSIM on individuals to determine whether chemical profiles showed significant similarity within individual mongooses. As we found evidence of individually distinct chemical profiles, we then conducted nested ANOSIMs to investigate similarity associated with other factors (sex, social group, season and reproductive status), with individual nested within other factors to control for pseudoreplication caused through repeat sampling of individuals. As reproductive status may influence males and females differently, we analysed the sexes separately when conducting ANOSIMs on reproductive data. Only females could become pregnant and enter oestrus, so the reproductive status of the individual concerned was only included for samples from females. To investigate whether the reproductive status of the group influences other individuals (e.g. whether pregnancy and oestrus of females influence male groupmates), we conducted nested ANOSIMs separately for males and females with individual identity and group reproductive status as the explanatory variables. Pairwise analysis of factors categories was also calculated through this analysis. For all ANOSIMs conducted there were 999 permutations to test the significance of R values and visualise any significant differences found using non-metric multidimensional scaling (MDS) plots from bootstrapped averages.

Chemical Diversity

We used Primer7 (version 7.0.23, PRIMER-e, https://www.primer-e.com/software) to calculate three measures of chemical diversity of each AGS profile (1) a count of the number of peaks within a sample (2) Pielou’s evenness index to assess how even the abundance of chemicals were across a sample and (3) Shannon’s diversity index that incorporates both richness and evenness of chemicals within a sample. To investigate whether the chemical diversity of the samples was associated with life history and seasonal information, we constructed general(ised) linear mixed effect models in R version 4.2.1 (R core team, 2025) using the lme4 package (Bates et al., 2015). Models of Pielou's and Shannon's diversity indices were fitted with gaussian distribution and count data was fitted with a Poisson distribution. All models were checked for homoscedasticity through plotting residuals against fitted values from this we only had to square Shannon's diversity index to avoid heteroscedasticity (see appendix 3). In all models, the identity of the individual the sample was from was included as a random effect. We also tested the interaction between sex and reproductive state as males and females might display different chemical patterns throughout the reproductive cycle however these were not significant and thus removed from final models. Extra models were constructed using samples collected from females to test the effect of individual reproductive status on AGS chemical diversity. These models did not contain sex or group reproductive period and were tested for homoscedasticity by plotting fitted against residuals (see appendix 4). As p-values are not automatically produced from the models, we used the drop1 function from lme4 to conduct chi squared tests that tests the full model against a model with a dropped factor to determine the factors significance (Bates et al., 2015). For all plots relating to chemical diversity we used the tidyverse package in R studio version 4.2.1 (Wickham et al., 2019, R core team, 2025).

Ethics

Samples were collected with permission from the Uganda Wildlife Authority (UWA/COD/96/05) and Uganda National Council for Science and Technology (NS69ES). This study was approved by Swansea University Ethics Committee (references: SU-Ethics-Staff-200219/113 and 1 2025 12648 11968).

Results

Analysis of Similarities

Our results show that there are significantly different AGS chemical compositions between individuals indicating a unique chemical profile that could enable recognition from conspecifics (table 1). We also found that there were significant differences between the sexes (table 1, Figure 5). While our ANOSIM found there was a significant difference between the seasons this difference was very small (table 1, figure 6). When using pairwise tests there was a larger significant difference found between the two wet seasons and a smaller yet significant difference between the high wet and dry season (see appendix 5b).

Table 1. ANOSIM output of different factors with the significant factors presented in bold.

Factor	R	p-value
Individual	**0.204**	**0.001**
Group	0.008	0.351
Sex	**0.147**	**0.001**
Group Reproductive Period - Female	-0.069	0.835
Group Reproductive Period - Male	-0.039	0.765
Season	**0.089**	**0.001**
Individual Reproductive Status - Female	-0.047	0.797

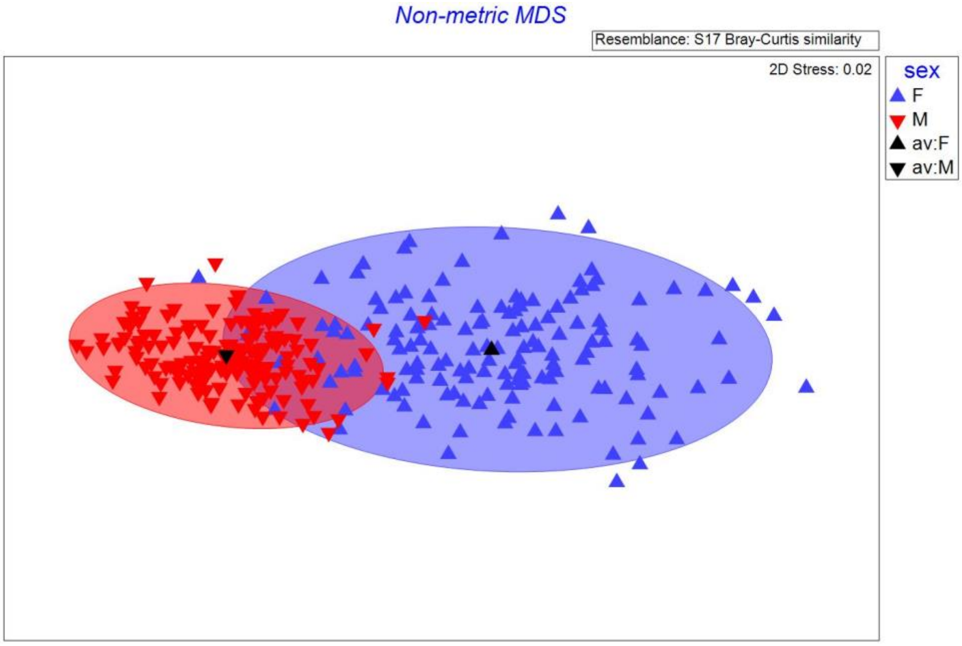

Figure 5. nMDS based on Bray-Curtis similarity of chemical diversity between males and females. Each coloured point represents a bootstrap with the black points being the average of all bootstraps. The ellipses encase 95% of bootstraps

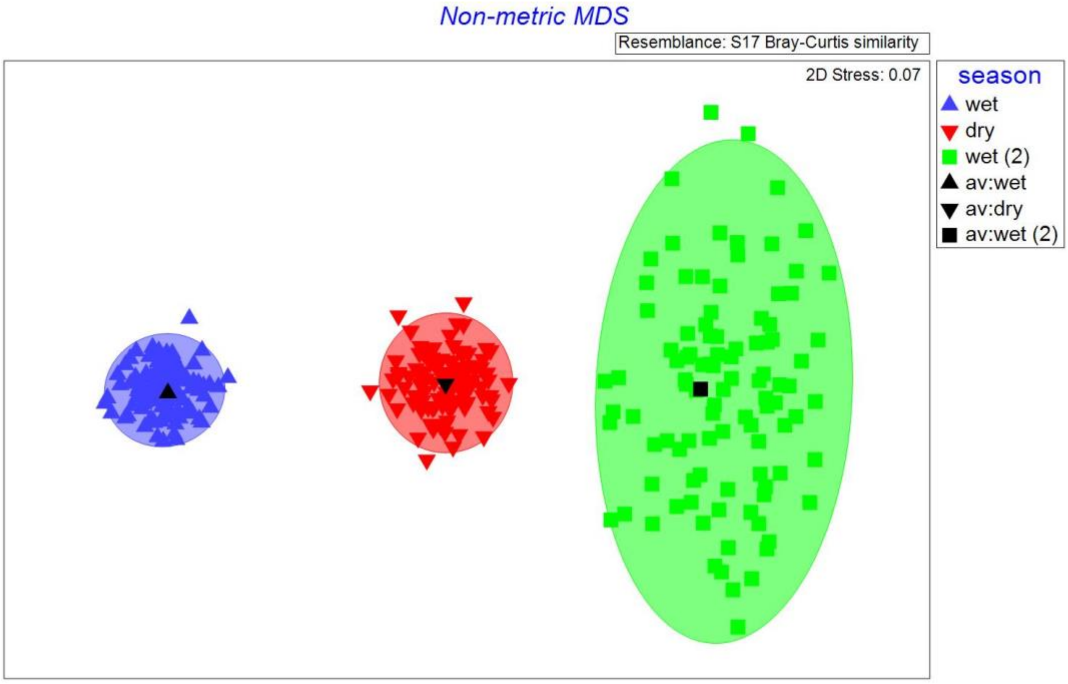

Figure 6. nMDS based on Bray-Curtis similarity of chemical diversity between the different seasons. Each coloured point represents a bootstrap with the black points being the average of all bootstraps. The ellipses encase 95% of bootstraps

Though we did not find any significant differences between all the groups (table 1) there were some instances where specific groups have small but significant differences (appendix 5a). Through pairwise tests the greatest group differences were observed between 1B and 24 (see appendix 5a). There were also no significant differences observed in group reproductive period (Table 1). However, within females while the output from our ANOSIM found no significant difference between individual female reproductive status, the pairwise tests we did identify a significant difference between pregnant females and females in oestrus (Figure 7).

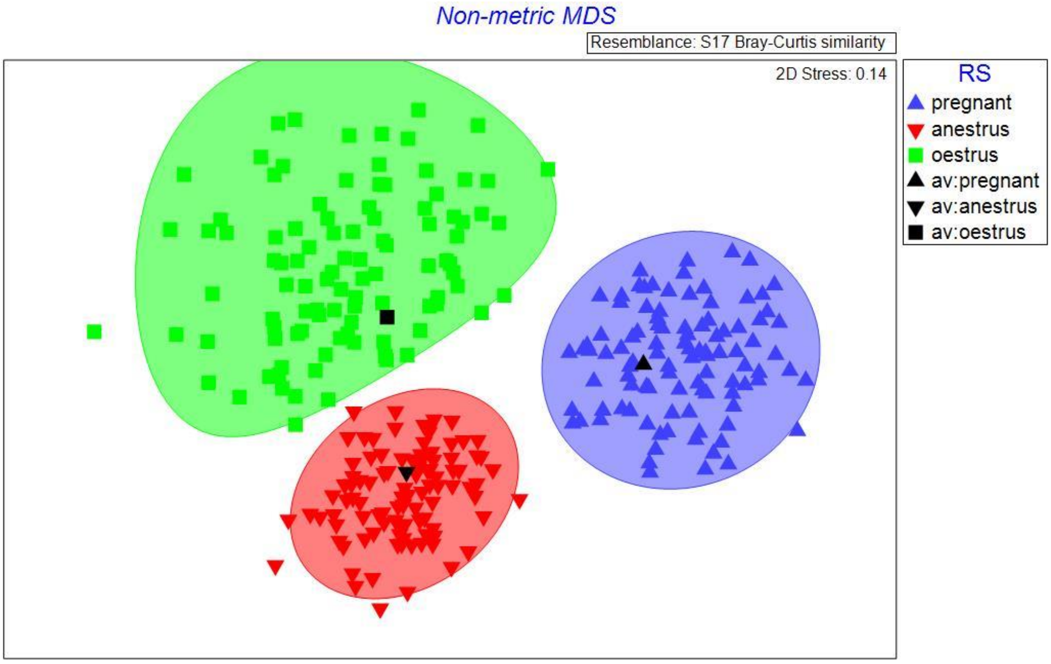

Figure 7. nMDS based on Bray-Curtis similarity of chemical diversity between the different reproductive states of individual females. Each coloured point represents a bootstrap with the black points being the average of all bootstraps. The ellipses encase 95% of bootstraps

Chemical Diversity

Our analysis found that across the 253 samples there were 319 peaks, with an average of 128.76 peaks per sample. The ages of individuals ranged from 14 days old to just under 10 years old with the mean age of individuals being 1.91 years. There was a negative relationship between Pielou's evenness and age showing the chemical abundances becoming less even as a mongoose ages (table 2, figure 8a). In relation to the number of chemicals within AGS, we found a positive correlation showing the number of chemicals increasing with age (table 3, figure 8b). There was also a positive relationship between Shannon's diversity index and age (table 4) however the gradient of the predicted values is shallower compared to the other two measures (figure 8c).

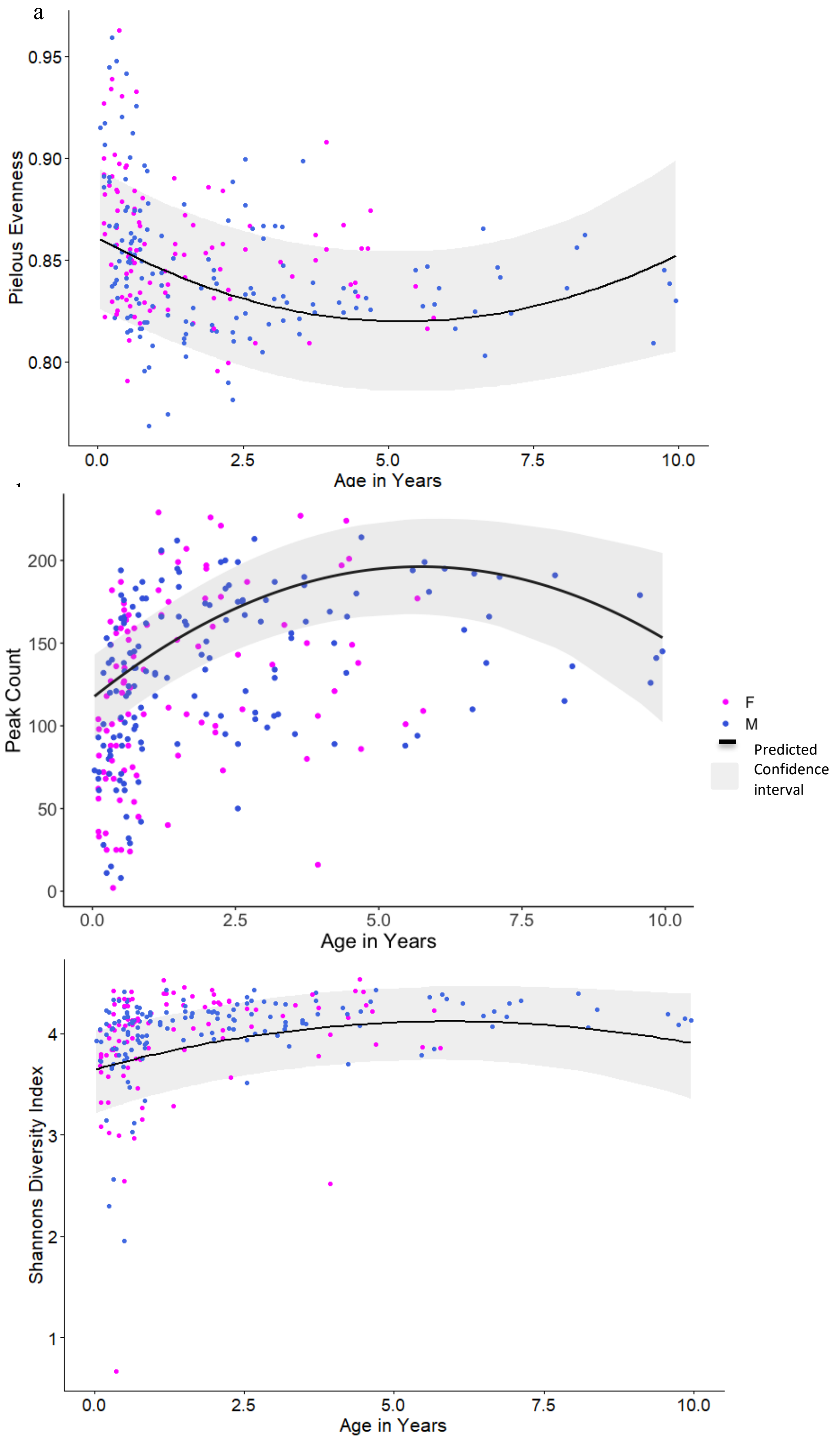

Figure 8. Individual's age against the a) Pielou's evenness b) number of chemicals in samples c) Shannon's diversity index. Prediction from each model is which is represented by solid black line with samples presented by points coloured by sex and a grey shaded area representing the model predicted 95% confidence intervals.

Table 2. Model output from LMM with Pielou’s evenness as response variable with all non-significant interactions removed. All p values were obtained from chi squared tests using the drop 1 function.

	Estimate	Std. Error	t value	p value
(Intercept)	0.868	0.016	52.993	
age	**-0.014**	**0.003**	**-4.762**	**1.645×10^{-6}**
age squared	**0.001**	**0.000**	**3.545**	**$2.876x10^{-4}$**
sex				0.068
sex (M)	-0.008	0.005	-1.749	
season				0.171
Season wet	-0.006	0.004	-1.458	
Season wet (2)	-0.017	0.010	-1.669	
group reproductive period				0.664
group oestrus	0.010	0.014	0.724	
group pregnant	0.006	0.014	0.406	
group				
group 1B	-0.005	0.009	-0.509	0.469
group 1H	0.003	0.007	0.405	
group 24	0.002	0.010	0.237	
group 26	0.008	0.011	0.783	
group 27	-0.007	0.009	-0.776	
group 31	0.020	0.022	0.919	
group 7A	0.014	0.009	1.609	

Table 3. Model output from GLMM with peak count as response variable and p values obtained from chi squared test. Significant factors shown in bold

	Estimate	Std. Error	z value	p value
(Intercept)	4.576908	0.114701	39.903	
age	**0.227804**	**0.039223**	**5.808**	**$2.255x10^{-8}$**
age squared	**-0.02209**	**0.005**	**-4.418**	**$1.315x10^{-5}$**
sex				0.319018
sex (M)	0.067895	0.068112	0.997	
season				**$5.8x10^{-10}$**
season wet	-0.07541	0.016543	-4.558	
season wet (2)	0.090242	0.036116	2.499	
group reproductive period				**$3.627x10^{-4}$**
group oestrus	0.125145	0.053896	2.322	
group pregnant	0.031155	0.059428	0.524	
group				0.117
group 1B	-0.16983	0.118361	-1.435	
group 1H	-0.24309	0.10505	-2.314	
group 24	-0.00919	0.137761	-0.067	
group 26	-0.11734	0.139148	-0.843	
group 27	-0.01339	0.11555	-0.116	
group 31	-0.01938	0.191052	-0.101	
group 7A	-0.27761	0.115961	-2.394	

Table 4. Model output from LMM with Shannon's diversity index as response variable and p values obtained from chi squared test. Significant factors shown in bold

	Estimate	Std. Error	t value	p value
(Intercept)	13.960	1.418	9.848	
age	**1.187**	**0.257**	**4.616**	**$3.312x10^{-6}$**
age squared	**-0.101**	**0.033**	**-3.080**	**0.002**
sex				0.490
sex (M)	0.257	0.402	0.639	
season				0.275
season wet	-0.555	0.380	-1.458	
season wet (2)	0.016	0.873	0.019	
group reproductive period				0.691
group oestrus	0.973	1.190	0.818	
group pregnant	0.972	1.239	0.785	
group				0.252
group 1B	-0.377	0.798	-0.472	
group 1H	-0.720	0.612	-1.178	
group 24	0.737	0.823	0.895	
group 26	-0.358	0.900	-0.397	
group 27	0.845	0.814	1.038	
group 31	2.262	1.868	1.210	
group 7A	-0.499	0.730	-0.683	

Across the testing period there were 115 samples collected in the dry season, 107 samples collected in high wet season and 31 collected in low wet season. There was no difference in Pielou's evenness (table 2) and Shannon's diversity index (table 4) between the wet seasons and dry seasons. Seasonality was only found to have significant impacts on the number of chemicals within the AGS samples (table 3, figure 9). During the low wet season there were slightly more chemicals within samples compared to the other seasons.

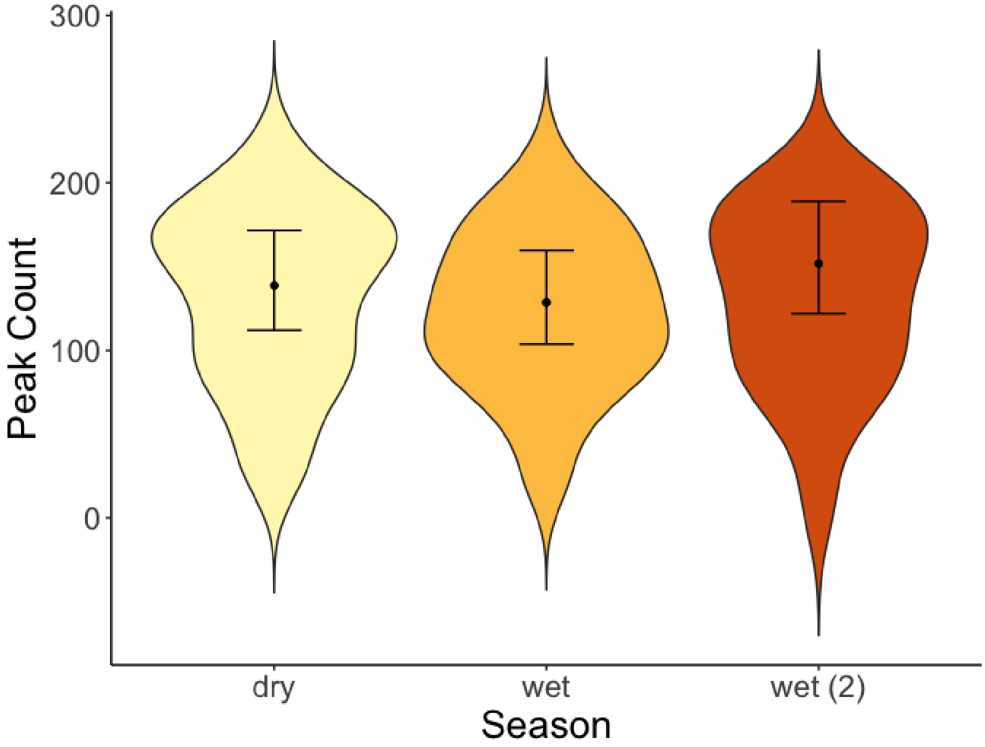

Figure 9. Relationship between the season and the number of peaks in each sample. The raw data is presented in violins with model predictions and 95% confidence intervals represented by solid black point and error bars respectively.

We took samples from 101 females and 152 males of which 181 samples that were taking during times when at least one female in a social group was pregnant, 59 during oestrus periods and the remaining 18 samples were taken while the reproductive period was or during anoestrus. Across all models there was no significant effect of the interaction between sex and group reproductive period on any diversity measure and therefore were removed from all models. When observing the effects of sex as a main effect there was also no significant effect on any chemical diversity measure (tables 2-4). However, when group reproductive period was tested as a main effect it was found to have a significant effect on the number of chemicals within a sample (table 3) but not the evenness of chemicals (table 2) or Shannon's diversity index (table 4). When females were pregnant there was a reduction in the number of chemicals in samples across the population and during oestrus periods there was an increase in chemicals (figure 10)

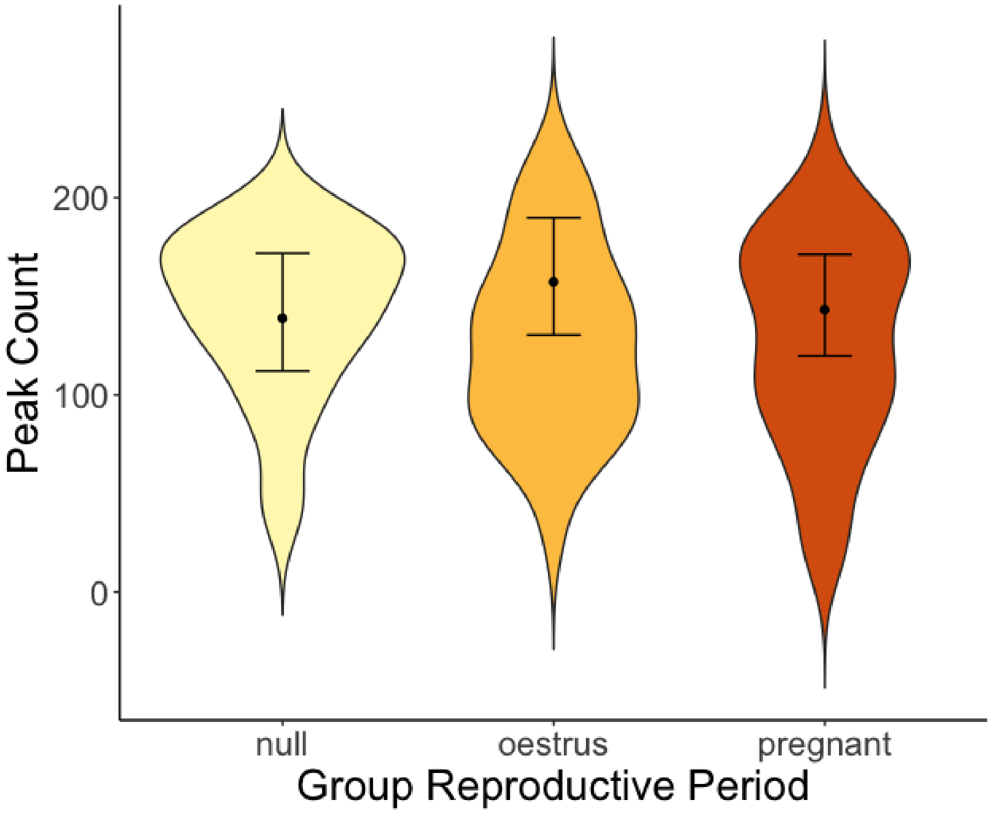

Figure 10. Differences of the peak count within chromatograms between the different reproductive periods. The rata presented in violins with the model predictions and 95% confidence intervals represented with a solid black point and error bars respectively.

From the models containing the samples obtained from the female individuals we found the same effects of age on all diversity measures and the same effect of season on the peak count. In this analysis we were also able to identify the effect individual reproductive status has on chemical diversity. Of the 101 females sampled from 21were in oestrus 27 were pregnant females and the remaining 53 were anoestrus. There was no significant effect of female reproductive status on Pielou's evenness (table 5) or Shannon's diversity index (table 7). The only measure of diversity that was affected by individual reproductive status was the peak count, with pregnant females having a significantly lower number of chemicals within their AGS than other females (table 6, figure 11).

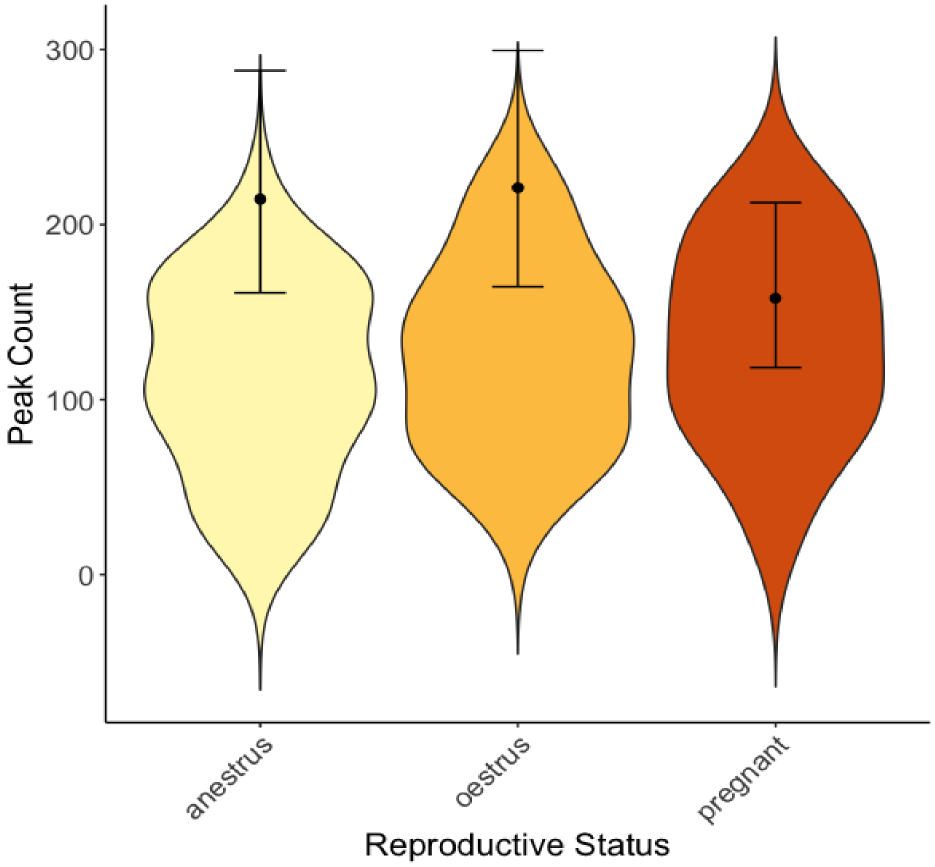

Figure 11. Differences of chromatogram peak counts between the different females reproductive states. The raw data is presented in violins with the predicted values and 95% confidence intervals from the model represented by solid black point and error bars

Table 5. Model output from LMM with Pielou's evenness as response variable using samples from females, p values were obtained from chi squared test with the significant factors are presented in bold.

	Estimate	Std. Error	t value	p value
(Intercept)	0.873	0.013	69.236	
age	**-10.120**	**3.908**	**-2.588**	**0.006**
age squared	**539.800**	**270.600**	**1.995**	**0.031**
female reproductive status				0.342
female oestrus	-0.001	0.011	-0.064	
female pregnant	0.013	0.010	1.243	
season				0.965
season wet	-0.001	0.007	-0.142	
season wet (2)	0.002	0.016	0.119	
group				0.699
group 1B	0.007	0.015	0.507	
group 1H	0.001	0.013	0.100	
group 24	0.000	0.014	0.004	
group 26	0.003	0.017	0.193	
group 27	-0.009	0.015	-0.557	
group 31	0.009	0.023	0.411	
group 7A	0.020	0.015	1.332	

Table 6. Model output from GLMM with peak count as response variable using samples from females, p values were obtained from chi squared test with the significant factors presented in bold

	Estimate	Std. Error	z value	p value
(Intercept)	4.407	0.168	26.222	
age	**0.897**	**0.109**	**8.205**	**7.679×10^{-16}**
age squared	**-0.169**	**0.023**	**-7.426**	**4.153×10^{-15}**
season				**6.114×10^{-6}**
season wet	-0.145	0.030	-4.838	
season wet (2)	-0.051	0.059	-0.876	
female reproductive status				**7.481×10^{-16}**
female oestrus	0.030	0.043	0.693	
female pregnant	-0.307	0.040	-7.747	
group				0.391
group 1B	-0.055	0.203	-0.273	
group 1H	-0.388	0.193	-2.016	
group 24	-0.069	0.219	-0.317	
group 26	-0.082	0.231	-0.354	
group 27	-0.032	0.219	-0.146	
group 31	-0.137	0.248	-0.553	
group 7A	-0.384	0.228	-1.682	

Table 7. Model output from LMM with Shannon's diversity index as response variable using samples from females, p values were obtained from chi squared test with the significant factors are presented in bold

	Estimate	Std. Error	t value	p value
(Intercept)	13.929	1.263	11.031	
age	**3.516**	**1.073**	**3.276**	**5.59x10-4**
age squared	**-0.543**	**0.203**	**-2.671**	**0.004**
season				0.418
season wet	-0.889	0.715	-1.244	
season wet (2)	-1.278	1.587	-0.806	
female reproductive status				0.236
female oestrus	0.365	1.100	0.332	
female pregnant	-1.550	1.035	-1.498	
group				0.236
group 1B	0.044	1.466	0.030	
group 1H	-1.471	1.257	-1.170	
group 24	1.488	1.391	1.070	
group 26	-0.173	1.689	-0.102	
group 27	0.927	1.543	0.601	
group 31	2.196	2.308	0.951	
group 7A	-0.368	1.537	-0.239	

Discussion

Here, we investigated the chemical composition of banded mongoose anal gland secretions (AGS). Through analysis of similarities, we found that individual mongooses possess unique chemical signals that are significantly distinct from others. Once these individual differences had been accounted for, we found no evidence of group-level chemical signatures. However, we did find differences between the sexes, and temporal differences, with samples collected within a season being more similar than samples collected between seasons. We also found that patterns of chemical diversity varied with age, female reproductive status and season.

Group and individual identity

Our study found evidence of individually distinct chemical profiles, suggesting that individual identity could be discerned from scent using individually distinct signature mixtures that are learned over time. This is in line with previous observational work where individuals appear to distinguish between familiar and unfamiliar conspecifics

(Jordan et al., 2010; Mitchell et al., 2018). With these results we corroborate findings in previous studies that also found individual signatures through field observations and GC-MS analysis (Jordan et al., 2011b; Jordan et al., 2011c). It is possible that individual-level signature mixes are related to genetic differences between individuals. Previous work has suggested multiple hypotheses on the relationship between major histocompatibility complex (MHC) on scent with the MHC molecules produced binding and transporting volatile compounds to urine or its influence on microbiomes (Singh, 2001; Milinski, 2022). Relationships between scent and MHC genotype have observed in the banded mongooses, with individuals responding differently to scents depending on the degree of MHC dissimilarity (Schubert et al., 2024). These outcomes are similar to other studies on other species suggest that this relationship has evolved as a potential mechanism to reduce inbreeding (Grogan et al., 2019).

The MHC can also mediate the microbiome which may in turn influence chemical composition of AGS through the fermentation hypothesis, whereby symbiotic bacteria within glands synthesise chemical odorants (Zhou et al., 2021). However the relationships between MHC, microbiome and odour still requires further investigation due to there being few studies testing the relationship between two of the factors but no study incorporating all three (Schubert et al., 2021). Banded mongooses provide an excellent opportunity to investigate covariation between MHC, microbiome and odour in future studies. Furthermore, areas of the genome other than MHC may also influence the production of chemicals found in AGS and therefore generate individually distinct chemical profiles. Supporting this possibility, banded mongooses have been shown to detect genetic relatedness in AGS (Mitchell et al., 2018) even when the odour donor is unfamiliar to themselves (Schubert et al., 2024). The detection of genetic relatedness was found to be unrelated to MHC genotype, suggesting that this is not simply the result of an association between MHC and the broader genome (Schubert et al., 2024). Future studies investigating the chemical basis of individual distinctiveness in banded mongooses would enable us to reveal the subsets of chemicals involved in generating individual signature mixes and the role of the genome and environmental variation in their persistence over time.

Contrary to our prediction, we found no evidence of a group-level chemical signatures within or between the 8 social groups sampled during this study. This was particularly interesting due to the territorial nature of banded mongooses which could lead to assumptions around group identification through scent. Research involving the closely related dwarf mongoose, *Helogale parvula,* has also suggested group signature scents but with no quantitative data on this it could also be the case that individual scents from unfamiliar individuals are presenting as group scents (Christensen et al., 2016). This outcome suggests that group signatures may not be the mechanism adopted by this species to identify non-group mongooses. Rather than groups having specific scents, individuals may learn the odours of group members through regular continued exposure to their scents. This mechanism of identifying group members from exposure to scent has been observed in behavioural experiments involving Damaraland mole-rat, *Cryptomys damarensis,* whereby individuals could no longer recognise clan members after periods of separation (Jacobs and Kuiper, 2000). Alternatively, it is possible that a lack of a group scent could be due to the limitations of GC-MS, with heavily polarised and larger molecules travelling through the column. Some molecules might simply be unable to withstand the harsh partitioning environment between stationary and mobile phases whereby molecules might not withstand the high temperatures or have strong reactions within the stationary phase preventing them from moving to the mobile phase and ultimately detection (Rockwood et al., 2018). However studies analysing large, non-volatile compounds like proteins are few but recent work on rodent individual identification through major urinary proteins has highlighted the use of olfactory proteins (Gómez-Baena et al., 2023). Furthermore, by using other techniques such as solid phase microextraction, the absorption of sample into a sorbent coated fibre, prior to GC-MS found group ID within the chemical profiles of African elephants and European badgers, *Meles meles* suggesting that this extraction method of analytes might capture macromolecules within samples (Noonan et al., 2019; von Dürckheim et al., 2022). While there is currently no fully comprehensive method that can analyse all metabolites and organic compounds due to chemical variation in physical properties there is scope that future studies begin to incorporate analysis of larger compounds in relation to scent communication. (Root-Gutteridge et al., 2025).

Age differences

Age was a major factor that influenced not only the number of potential chemicals within AGS but also the abundances of chemicals within the samples (reflected in its significant impact on all three measures of chemical diversity). In all cases, there is a change in the trajectory at ~5 years which might reflect changes in social dominance, with males typically reaching reproductive peak between 3-4 years and females between 2-3 years and the likelihood of being aggressively evicted from their social group dropping after these periods (Cant et al., 2016). The changes in chemical composition of AGS with age might be caused by hormones that trigger the production of sex specific pheromones or substances to signal sexual maturation (Caspers et al., 2011). In this study the mean age of mongooses sampled was 1.97 years compared to the typical lifespan of wild banded mongooses where males live for ~3.5 years and females ~3.2 years on average (Cant et al., 2016). Therefore, with a lack of data points from older individuals understanding how the chemical diversity changes beyond these ages in this work are based on model predictions from the relatively few samples from individuals. Future work would benefit from additional samples from older age groups and from collecting multiple samples from the same individuals over a longer period to investigate how chemical profiles change within individuals as they age.

Sex differences

We did observe differences between the sexes through ANOSIM a result that supports the observational work on banded mongooses and their ability to detect sex through scent (Jordan et al., 2011a). However, it was surprising that there was no effect on the diversity as it could be assumed that these differences would be linked to differences in chemical diversity. Differences in diversity have been found in other mammalian species such as the crowned lemur, *Eulemur coronatus,* with males having significantly more peaks than females (Elwell et al., 2021). This work on lemurs also identified compounds that were present in female, males or both sexes an aspect we did not investigate in the present study. These findings could again be due to the limitations of GC-MS or the lack of chemical identification.

Female Reproductive Status

Through this research we have identified the impact female reproductive status has on individual chemical profiles and on the scent of other group members. With females scents having fewer chemicals within AGS during pregnancy which could the cause for the behavioural changes in response to pregnant females scents (Mitchell, 2017). In banded mongooses this change in chemical diversity could be the result of increased glucocorticoid steroid concentrations during pregnancy (Sanderson et al., 2015a), and there is evidence to suggest that stress can be presented in mammalian odours (Lerch et al., 2016). Alongside stress there are other energetic drains associated with pregnancy which could result in the reduction of chemicals within AGS as females may have diverted energy towards other processes such as mammary gland development and gestation (Meniri et al., 2022).

Not only did female reproductive status have effects on the individual but it also likely had effects on other members of the group. During oestrus there was an increase in chemicals when observing females individually as well as the group reproductive period. This increase could be due to the production of a chemical unique to oestrus similar to the oestrogen dependent sex pheromone produced in proestrus and oestrus in mice (Achiraman et al., 2010). Changes in chemical diversity during oestrus could also be due to the changes in scent marking frequency in both males and females observed (Jordan et al., 2011a). Female’s scents might also change during this period as overmarking other female scents might aid in obtaining better quality male or benefit subordinates to coordinate synchronous births (Gilchrist, 2006; Hodge et al., 2011; Jordan et al., 2011c). With our findings only being significant when group reproductive period was included as a main effect and not in an interaction it seems that both sexes show a similar pattern in chemical diversity depending on the groups reproductive period. Though we identify these changes, understanding what these changes are caused by or the specific chemicals involved requires further investigation.

Seasonal influences on chemical diversity

With there being seasonality observed in the banded mongooses pregnancies and pup survivorship coinciding with rainfall it is possible that scent marking might be seasonal to achieve high reproductive success (Khera et al., 2023; Khera et al., 2025b). Here we have found that the season influences the number of peaks however the change in peak count was different for both seasons with one wet season resulting in an increase and the other causing a decrease in the peak count compared to the dry season. One possible explanation is that change in chemical diversity might be due to changes in resource availability impacting the chemical composition of AGS. Banded mongoose diet varies seasonally and during periods of high ambient temperatures, banded mongooses forage less (Rood, 1975; Khera et al., 2025a). These shifts in foraging behaviour and diet could result in changes in the compounds within AGS. Changes from diet can influence odours in various ways such as resource quality influencing health and potential influences on the microbiome that produce volatile compounds or even the metabolites from gland cells (De Kock et al.; Douglas and Dobson, 2013; Henneken et al., 2017). There has been some work involving desert locusts, *Schistocerca gregaria*, and house mice, *Mus musculus,* that find production of volatile odorants are dietary by-products that are amplified by bacteria metabolism providing some evidence that diet can mediate scent composition (Ezenwa and Williams, 2014).

One caveat to the idea of diet influencing gland microbial communities is that most of the knowledge on this subject is derived from gut microbiomes, which are directly influenced by diet. In the current study we use AGS which may have less opportunity to be influenced by diet. Supporting this a study observing giant pandas did identify the contrast between gut microbiome and AGS indicating that scent gland microbiomes may remain consistent despite dietary changes (Zhou et al., 2021). However, studies on microbiomes within glands remain limited and future work on the species, and community of microbes along with the factors influencing them would expand our understanding on their involvement in chemical communication.

Perhaps one of the most important factors to understand and monitor are the influences of season on scent communication. With accelerated rates of climate change and recent work uncovering the negative effects of increased temperature on the efficiency and efficacy of chemical signals this factor could impact many species across all environments (Iglesias-Carrasco et al., 2018; Gérard et al., 2023). The effect climate change and urbanisation might have on mammalian scent communication is still to be researched, but with its connections to diet and reproduction it is likely that increase in temperatures or a shift in rainfall might impact chemical communication.

Conclusion

Overall, the findings from this research have revealed that chemical profiles of banded mongooses are mediated by an individual's age, sex and female reproductive status. Through this work we have highlighted the significant impact of age on an individual's chemical profile however the reasons behind these changes over time are still unknown. Possible causes for these developments in scent might stem from the sexual maturation of individuals or though the influence of the environment. We have also found that individuals do have unique chemical signatures which reinforces previous work that used both field observations and chemical analysis supporting the hypothesis that banded mongooses use unfamiliar and familiar scents to recognise group members. It has also been identified in this study that there are seasonal impacts on scent that could be the result of changes in resource availably affecting an individual's diet, but further investigation into this relationship between scent and season is needed. While this work has provided an insight into the chemical basis of scent communication, this area of study is still developing. With the incorporation of microbiome, MHC and diet there is potential to gain greater understanding on the underlying mechanisms involved in scent communication.

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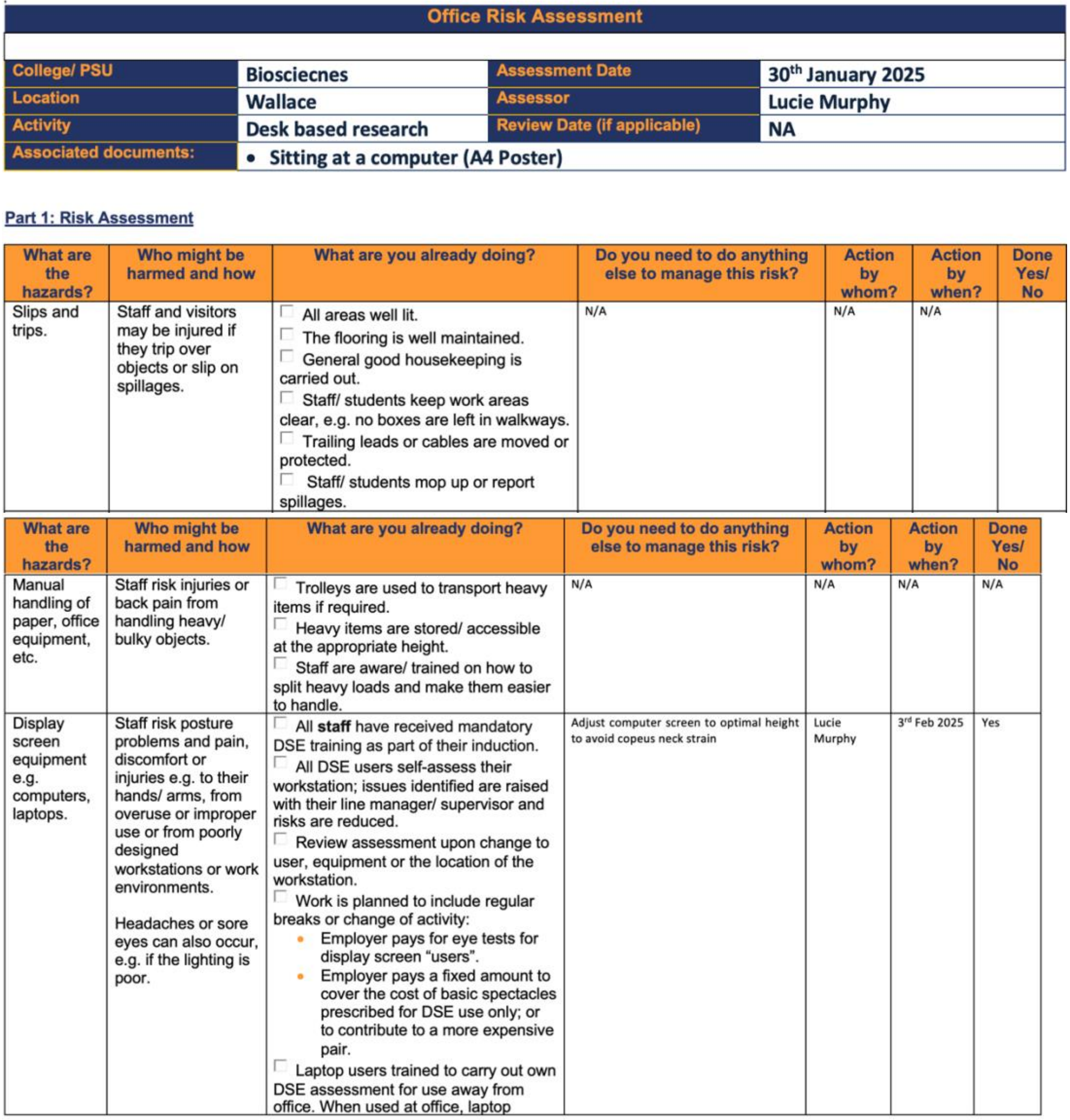
Appendices

Appendix 1 – Risk assessment



Office Risk Assessment

College/ PSU	Biosciecnes	**Assessment Date**	30th January 2025
Location	Wallace	**Assessor**	Lucie Murphy
Activity	Desk based research	**Review Date (if applicable)**	NA
Associated documents:	• Sitting at a computer (A4 Poster)		

Part 1: Risk Assessment

What are the hazards?	Who might be harmed and how	What are you already doing?	Do you need to do anything else to manage this risk?	Action by whom?	Action by when?	Done Yes/ No
Slips and trips.	Staff and visitors may be injured if they trip over objects or slip on spillages.	☐ All areas well lit. ☐ The flooring is well maintained. ☐ General good housekeeping is carried out. ☐ Staff/ students keep work areas clear, e.g. no boxes are left in walkways. ☐ Trailing leads or cables are moved or protected. ☐ Staff/ students mop up or report spillages.	N/A	N/A	N/A	
Manual handling of paper, office equipment, etc.	Staff risk injuries or back pain from handling heavy/ bulky objects.	☐ Trolleys are used to transport heavy items if required. ☐ Heavy items are stored/ accessible at the appropriate height. ☐ Staff are aware/ trained on how to split heavy loads and make them easier to handle.	N/A	N/A	N/A	N/A
Display screen equipment e.g. computers, laptops.	Staff risk posture problems and pain, discomfort or injuries e.g. to their hands/ arms, from overuse or improper use or from poorly designed workstations or work environments. Headaches or sore eyes can also occur, e.g. if the lighting is poor.	☐ All **staff** have received mandatory DSE training as part of their induction. ☐ All DSE users self-assess their workstation; issues identified are raised with their line manager/ supervisor and risks are reduced. ☐ Review assessment upon change to user, equipment or the location of the workstation. ☐ Work is planned to include regular breaks or change of activity: • Employer pays for eye tests for display screen "users". • Employer pays a fixed amount to cover the cost of basic spectacles prescribed for DSE use only; or to contribute to a more expensive pair. ☐ Laptop users trained to carry out own DSE assessment for use away from office. When used at office, laptop	Adjust computer screen to optimal height to avoid copeus neck strain	Lucie Murphy	3rd Feb 2025	Yes

What are the hazards?	Who might be harmed and how	What are you already doing?	Do you need to do anything else to manage this risk?	Action by whom?	Action by when?	Done Yes/ No
		should be used with docking station, screen, keyboard and mouse.				
Working at height e.g. filing on top shelves, etc.	Falls from any height can cause bruising and fractures.	☐ Where possible the storage of items at height is avoided. ☐ A step ladder is available if staff need to access items on high shelves, etc. ☐ Step ladders are inspected, to ensure they remain safe to use.	N/A	N/A	N/A	N/A
Health of workers in the office environment .	All staff could be affected by factors such as, lack of job control, bullying, not knowing their role, etc.	☐ Staff/ students have management/ supervisory help to understand what their duties and responsibilities are. ☐ Staff/ student can speak confidentially to a manager or supervisor if they are feeling unwell or uneasy about things at work. ☐ Change is managed and communicated effectively. ☐ Systems are in place to ensure demands are reasonable. ☐ Signpost staff to mental health assistance and professional mental health services should they require them (see University Guidance - Health and Wellbeing).	N/A	N/A	N/A	N/A
Electrical	Staff could get electrical shocks or burns from using faulty electrical equipment. Electrical faults can also lead to fires.	☐ Staff/ students are trained to spot and report any defective plugs, discoloured sockets or damaged cable/ equipment. ☐ Defective equipment taken out of use safely and promptly replaced. ☐ Staff/ students are told not to bring in their own appliances, toasters, fans, etc. Electrical appliances are PAT tested.	N/A	N/A	N/A	N/A
Fire	If trapped, staff could suffer fatal injuries from smoke inhalation/ burns.	• A Fire risk assessment has been completed and adequate fire safety measures are in place. • Evacuation plan has been implemented and tested. • Fire alarm tested regularly. • Fire drills carried out at least once a year. ☐ **All staff** have received mandatory fire awareness training as part of their induction. ☐ Regular checks made to ensure escape routes and fire exit doors are not obstructed. ☐ Combustible materials are stored safely. ☐ Waste is removed regularly.	N/A	N/A	N/A	N/A
Work equipment including, photocopier, printers, paper	Staff could get electrical shocks or burns from using faulty electrical equipment.	☐ All new equipment checked before first use to ensure there are no obvious accessible dangerous moving parts, or siting of the equipment does not cause additional hazards. ☐ Staff/ students trained in use of	N/A	N/A	N/A	N/A

What are the hazards?	Who might be harmed and how	What are you already doing?	Do you need to do anything else to manage this risk?	Action by whom?	Action by when?	Done Yes/ No
shredders, guillotines, etc.	Staff may also suffer injury from moving parts of equipment or unbalanced equipment.	equipment where necessary. ☐ Checks in place to ensure new staff/ students are trained to use equipment. ☐ Staff encouraged to spot and report any defects. ☐ Defective equipment is taken out of use safely and promptly replaced.				
Cleaning	Staff risk skin irritation or eye damage from direct contact with cleaning chemicals. Vapour from cleaning chemicals may cause breathing problems.	☐ Offices are cleaned by trained cleaning staff. **If cleaning is carried out by office users:** ☐ Cleaning products marked 'irritant' have been replaced by milder alternatives where available. ☐ Mops, brushes and protective gloves are provided and used, if required. ☐ Staff are shown how to use cleaning products safely. ☐ Cleaning materials are stored in a safe location.	N/A	N/A	N/A	N/A
Asbestos	When materials that contain asbestos are disturbed or damaged, fibres are released into the air. When these fibres are inhaled they can cause serious diseases (e.g. mesothelioma, asbestosis, lung cancer and pleural thickening).	• An asbestos survey has been carried out. • Office users must not carry out building maintenance activities, these are to be arranged through the Estates Helpdesk • If asbestos is considered present, planned measures are in place to manage asbestos and warn visiting workers etc.	N/A	N/A	N/A	N/A
Disabled worker. New or expectant mother. Young person/ child. Lone worker.	These workers may be at increased risk in the office environment	☐ Manager agrees action plan to address any specific needs: **Disabled worker** ☐ Managers/ supervisors to check if vulnerable staff/ students can use the main means of escape. ☐ Personal Emergency Evacuation Plans (PEEPS) are in place for staff/ students requiring assistance. ☐ Check if staff/ students have any pre-existing medical conditions (e.g. asthma or other breathing difficulties; back or other joint/ muscle conditions, etc.) that may be made worse by things in the office. ☐ Reasonable adjustments are made. **Pregnant person, new or breastfeeding parent** ☐ Risk assessments are carried out. Refer to the University's Pregnant Persons, New & Breastfeeding Parent Hazard Guidance and Risk Assessment Policy Arrangements ☐ Processes/ working conditions altered when necessary to reduce risks to new or expectant parent. ☐ Rest room facilities are available for breastfeeding parents. **Young person/ child** ☐ All staff to be aware that young colleagues may be inexperienced or lack awareness of risks. ☐ Processes/ working conditions altered when necessary to reduce risks to young persons/ child. **Lone worker** ☐ Lone worker risk assessments are carried out. Refer to the University's lone working policy arrangements ☐ Lone workers use SafeZone.	N/A	N/A	N/A	N/A

Appendix 2 – Ethics approval

Swansea University
Prifysgol Abertawe

Approval Date: 14/02/2025

Research Ethics Approval Number: 1 2025 12648 11968

Thank you for completing a research ethics application for ethical approval and submitting the required documentation via the online platform.

Project Title	Understanding underlying factors of scent communication
Applicant name	MISS LUCIE MURPHY
Submitted by	MISS LUCIE MURPHY /
Full application form link	https://swansea.forms.ethicalreviewmanager.com/Project/Index/14947

The Science and Engineering ethics committee has approved the ethics application, subject to the conditions outlined below:

Approval conditions

1. The approval is based on the information given within the application and the work will be conducted in line with this. It is the responsibility of the applicant to ensure all relevant external and internal regulations, policies, and legislations are met.
2. This project may be subject to periodic review by the committee. The approval may be suspended or revoked at any time if there has been a breach of conditions.
3. Any substantial amendments to the approved proposal will be submitted to the ethics committee prior to implementing any such changes.

Specific conditions in respect of this application:

The application has been classified as Low Risk to the University.

No additional conditions.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees. It complies with the guidelines of UKRI and the concordat to support Research Integrity.

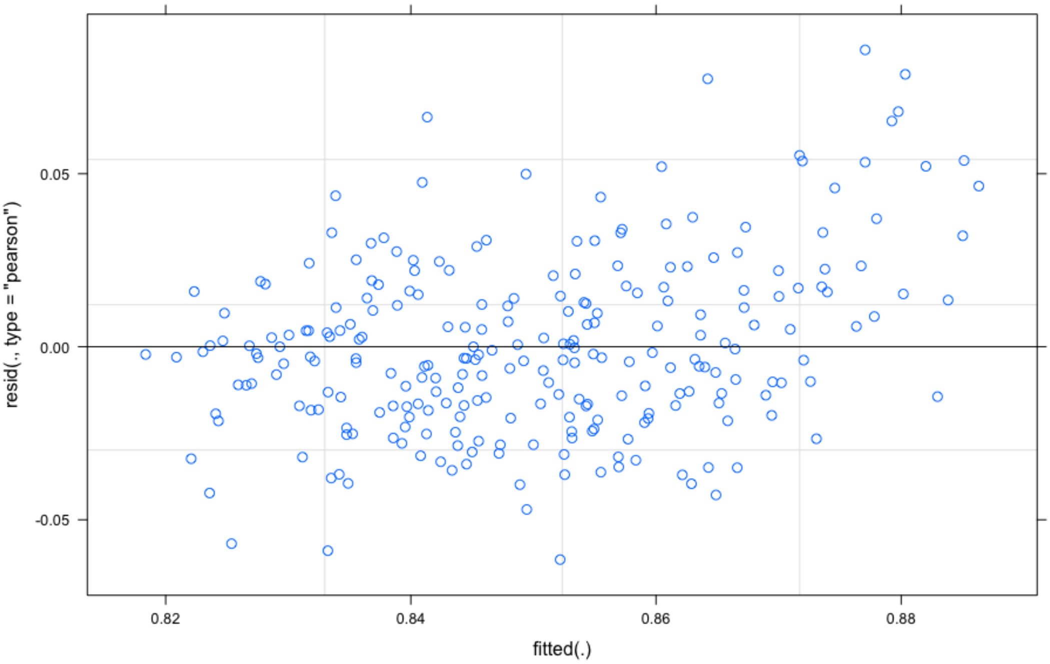
Science and Engineering Research and Ethics Chair

Swansea University.

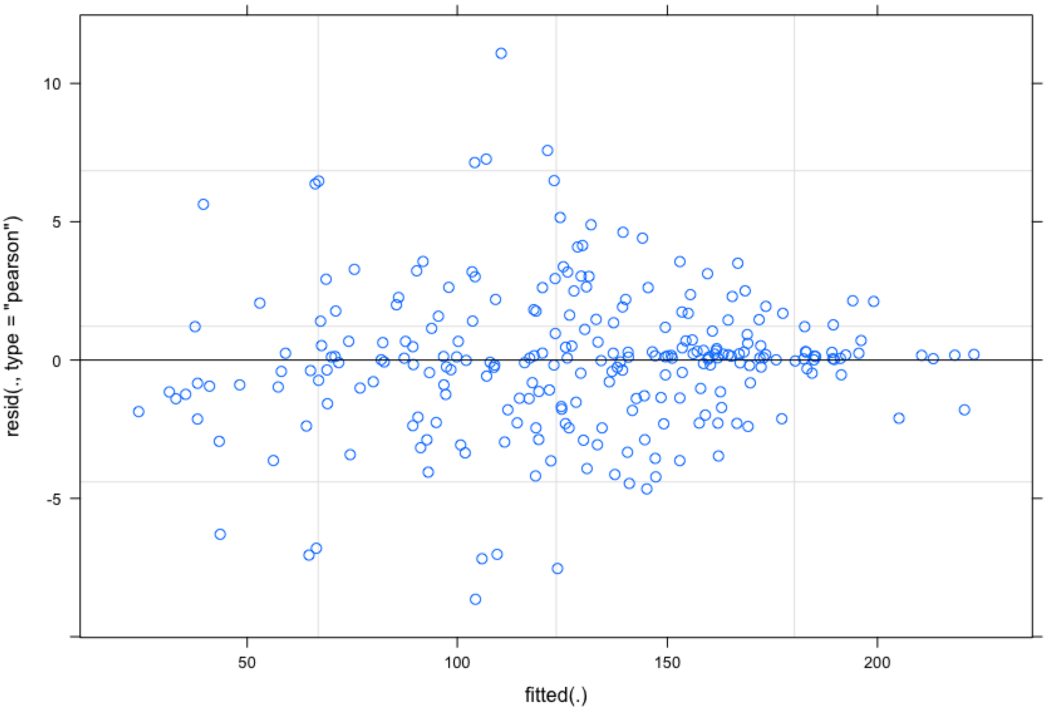
If you have any queries regarding this notification, then please contact your research ethics administrator for the faculty.

- For Science and Engineering contact FSE-Ethics@swansea.ac.uk
- For Medicine, Health and Life Science contact FMHLS-Ethics@swansea.ac.uk
- For Humanities and Social Sciences contact FHSS-Ethics@swansea.ac.uk

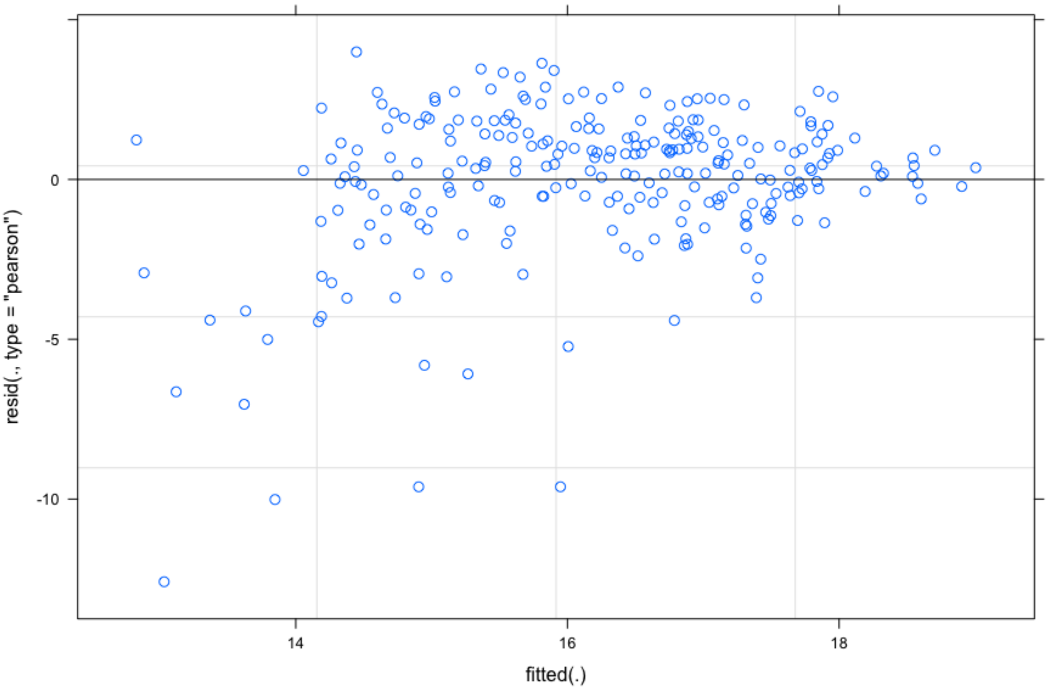
Appendix 3 – Fitted vs residual plots



Appendix 3a. fitted vs residual values derived from model with Pielou's evenness as response variable in a general linear mixed effect model using full dataset.

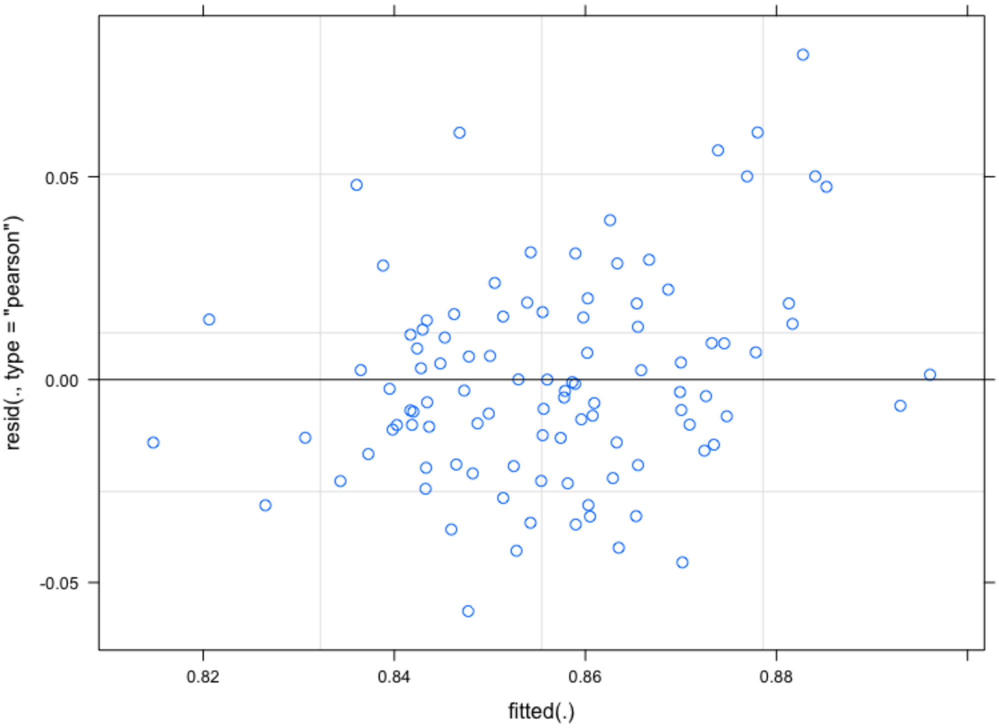


Appendix 3b. fitted vs residual values derived from model with peak count as response variable in a generalised linear mixed effect model using full dataset.

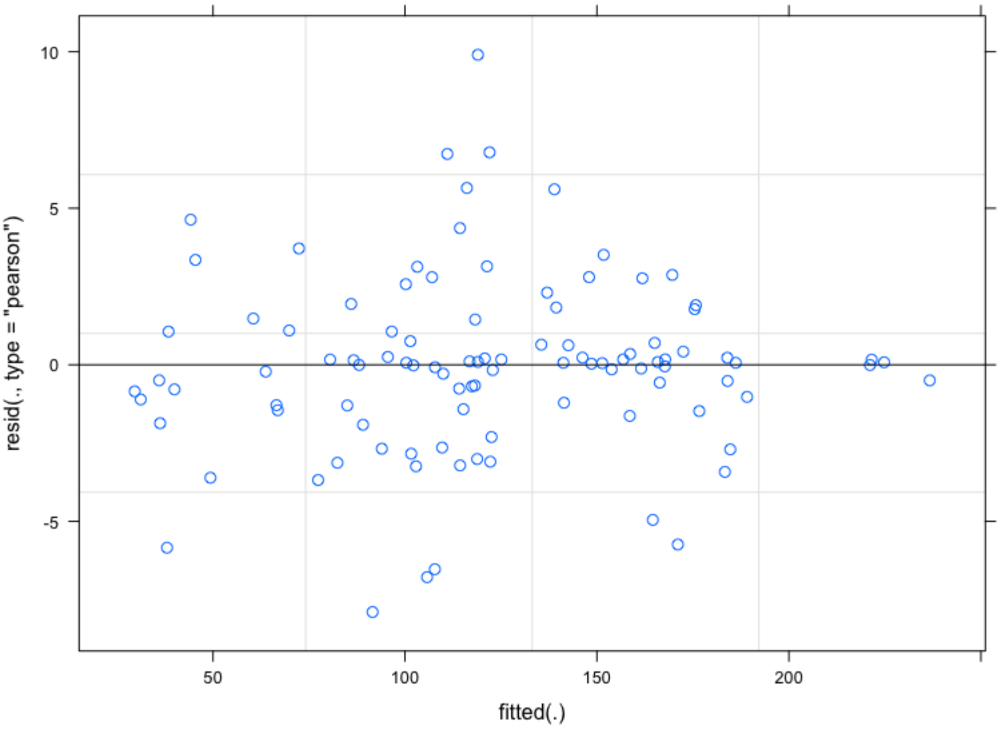


Appendix 3c. fitted vs residual values derived from model with Shannon's diversity index as response variable in a general linear mixed effect model using full dataset

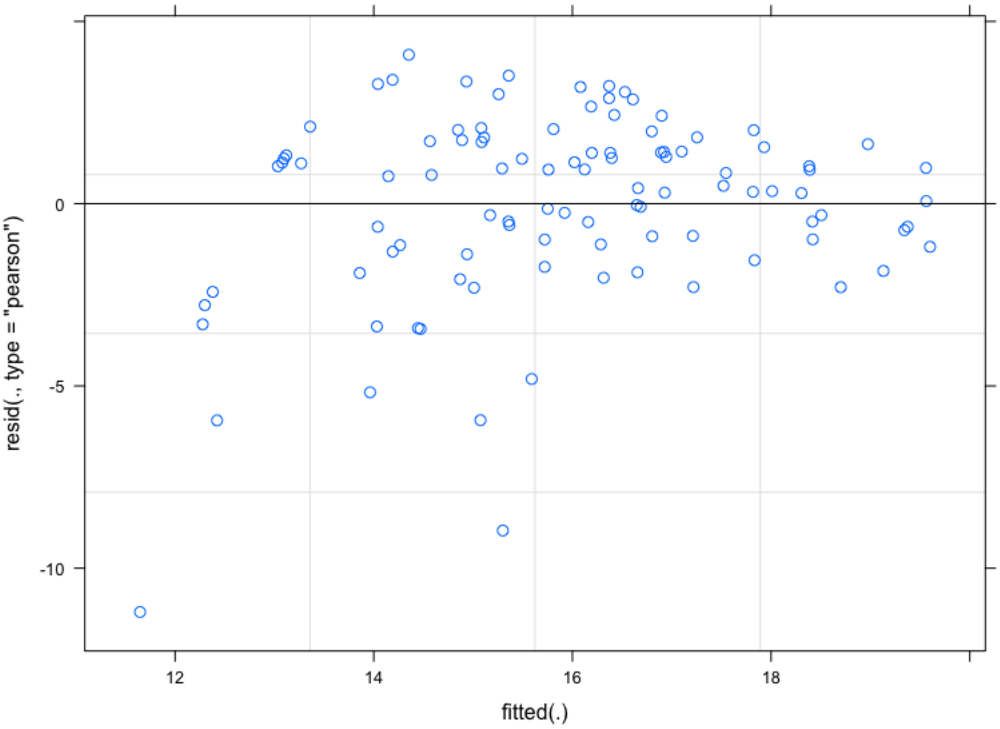
Appendix 4 – Fitted vs residual plot, female only models



Appendix 4a. fitted vs residual values derived from model with Pielou's evenness as response variable in a general linear mixed effect model using data from females only



Appendix 4b. fitted vs residual values derived from model with peak count as response variable in a general linear mixed effect model using data from females only



Appendix 4c. fitted vs residual values derived from model with Shannons diversity index as response variable in a general linear mixed effect model using data from females only

Appendix 5 – Pairwise tests

Appendix 5a. Pairwise test result between all groups within the dataset, each with 999 permutations

Groups	R Statistic	p value
24, 31	-0.142	0.9
24, 26	0.031	0.21
24, 27	0.07	0.189
24, 1B	**0.134**	**0.049**
24, 7A	-0.077	0.836
24, 1H	-0.057	0.698
24, 19	0.045	0.271
31, 26	-0.028	0.539
31, 27	-0.07	0.649
31, 1B	0.047	0.353
31, 7A	-0.23	0.97
31, 1H	-0.192	0.905
31, 19	-0.137	0.82
26, 27	-0.029	0.588
26, 1B	0.038	0.276
26, 7A	-0.061	0.78
26, 1H	-0.071	0.731
26, 19	-0.005	0.479
27, 1B	0.032	0.068
27, 7A	**0.035**	**0.046**
27, 1H	0.01	0.315
27, 19	-0.001	0.461
1B, 7A	**0.068**	**0.004**
1B, 1H	0.017	0.281
1B, 19	0.078	**0.002**
7A, 1H	0.047	0.133
7A, 19	**0.051**	**0.023**
1H, 19	0.008	0.326

Appendix 5b. Pairwise test result between the three seasons within the dataset, each with 999 permutations

Groups	R	p-value
wet, dry	**0.055**	**0.001**
wet, wet (2)	**0.259**	**0.002**
dry, wet (2)	0.045	0.221

Appendix 5c. Pairwise test result between different stages of female reproductive cycle, each with 999 permutations

Groups	R Statistic	p-value
pregnant, anoestrus	-0.045	0.806
pregnant, oestrus	**0.086**	**0.015**
anoestrus, oestrus	-0.019	0.56

Appendix 6 – Datasets

Banded mongoose scent communication data access