Understanding the behaviour of Male Asian Elephants (*Elephas maximus*) in a human-dominated landscape

A Thesis

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by

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INDIAN INSTITUTE OF SCIENCE EDUCATION AND RESEARCH PUNE

Certificate

This is to certify that this dissertation entitled Understandin the behaviour of male Asian Elephants(*Elephas maximus*) in a human-dominated landscape towards the partial fulfilment of the BS-MS dual degree programme at the Indian Institute of Science Education and Research, Pune represents study/work carried out by Vidisha Hate Indian Institute of Science Education and Research under the supervision of Prof Raman Sukumar, Professor, Centre for Ecological Sciences, during the academic year 2023-2024.

Prof Raman Sukumar

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Prof Raman Sukumar

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This thesis is dedicated to Chai,

My inspiration and motivation to do everything!

Declaration

I hereby declare that the matter embodied in the report entitled " Understanding the behaviour of Male Asian Elephants (*Elephas maximus*) in a Human-dominated Landscape" are the results of the work carried out by me at the Department of Biology , Indian Institute of Science Education & Research (IISER) Pune, under the supervision of Prof Raman Sukumar, and the same has not been submitted elsewhere for any other degree. Wherever others contribute, every effort is made to indicate this clearly, with due reference to the literature and acknowledgement of collaborative research and discussions.

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1. Abstract

Asian elephants can exhibit complexity in social behaviour due to their longevity, behavioural plasticity and high cognitive abilities. Consequently, various behavioural changes have been studied in this species, including males exhibiting association in all-male groups in human-dominated areas as a response to increasing anthropogenic pressure. These associations highlight the importance of male sociality in shaping an individual's social behaviour and enhancing their body condition and reproductive success. The state of musth, characterised by increased levels of androgens in male elephants, is a significant factor affecting the behaviour and physiology of an individual male. Therefore, for this study, we selected 47 bulls from our study area to assess whether or not musth affects the spatial distribution of male Asian elephants in the eastern ghats of Karnataka. We found that younger males (N=20) exhibit a staggered musth pattern compared to long and continuous musth periods in older males (N=27). Moreover, Adolescents and young adult males maintain longer distances from older adults in musth (P=0.268, difference in medians of distances(m), N=1957). Further, irrespective of the maturity status, all males, when in musth, were found closer to herds (P<0.01, difference in medians of distances(metres), N=2528). Finally, on analysing at an individual level, we found that even though at a population level, one may observe a pattern in the effect of musth on the spatial distribution of male elephants, a similar pattern may not hold at an individual level which maybe due to the idiosyncratic behaviours of the individuals. Musth in elephants has been a topic of detailed research in both Asian and African elephants. However, analysis of the effect of musth spatially at the scale of a landscape has probably been conducted for the first time through this study. Since our study area also comprises locations with high human activity, we also examined the vocal repertoire of elephants in a high-human use area. We found out that the vocal activity of elephants in a human-dominated area is high during the night, and the repertoire has a higher proportion of calls like trumpets, roar-rumbles and chirps that are often produced in response to threat and display of annoyance and agression towards conspecifics as well as other species.

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3. Contributions

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Prof Raman Sukumar, Dr Nishant Srinivasiah, Dr Nachiketha Sharma	Supervision
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Indian Institute of Science, FERAL and NIAS	Funding acquisition

Chapter 1 : Introduction

Elephants have roamed our planet for over 6 million years, with three living species currently inhabiting the natural environment: the African Savannah Elephant(*Loxodonta africana*), the African Forest Elephant (*Loxodonta cyclotis*) and The Asian Elephant (*Elephas maximus*).
The Asian Elephant is the closest living descendant to the woolly mammoth (Roca et. al,2015), discontinuously spread across different parts of South and Southeast Asia with a population of 48,323-51,680 individuals free-ranging in the wild (reference). Moreover, India alone houses over 60% of this population, with 29,964 individuals spread across the country's Northern, Southern, Central and North-Eastern parts.(Menon&Tiwari,2019)
They can be easily distinguished from their African counterparts as they differ in several morphological features due to evolutionary adaptation to their different environments and ecological niches (Soshani&Eisenberg,1982). African elephants have larger ears that serve as effective thermoregulatory structures, while the ears of Asian elephants are smaller and rounded (Roca et al.,2005). Furthermore, the trunk of an Asian elephant has only a single finger-like projection at its tip, while the African elephants have two (Sukumar,2006). Asian elephants also have dome-like structures on their head, absent in African elephants. (Sukumar,2003).
However, irrespective of the species, one thing rings true for every elephant that walks the earth: their success rests on the strength of their relationships!

Social organisation and sociality in elephants:

Elephants live in mixed-sex social units called families, bond groups, clans or herds. The mixed-sex herds are mainly comprised of mothers, aunts, daughters of all ages, and sons of pre-pubertal age (Hamilton,1972; Sukumar,2003; DeSilva&Wittemyer,2012)

The African elephant society is matriarchal/ female-centred in nature.(Hamilton,1972) This means that the matriarch (the oldest female of the family) plays a crucial role in decision-making regarding movement towards food and water, threat avoidance, conflict mitigation, and knowledge transfer(de Silva& Wittemyer,2012). Their high cognitive abilities allow elephants to exhibit complex and dynamic social bonds that are often affected by resource availability(Foley et al.,2008), anthropogenic pressure(Fernando et al.,2008) and even their physiological state(Poole&Granli,2011, Srinivasiah et al.,2019)

Male-Elephant Sociality:

Once the young male individuals hit puberty(14-15 years), they disperse from their natal herd and range freely inside the forest as solitary individuals.(Hamilton,1972; Sukumar,2003; DeSilva&Wittemyer,2012)

Moreover, some male elephants associate with all-male groups while traversing a human-dominated landscape.(Evans et al.,2008; Srinivasiah et al.,2019)

Due to their high cognitive abilities, elephants have complex sociality. Studies on male elephants' association in an all-male group revealed that these associations are crucial for an individual male to practice appropriate social behaviour, find and use resources and enhance his physiological conditions(Chiyo et al.,2014; Srinivasiah et al.,2019). There have been several studies on African elephants(Chiyo et al.,2011; Allen et al.,2020) and captive Asian elephants(Readyhough et. al,2023) on male sociality, suggesting that younger males prefer to associate with males of the same age class as them due to the similarities in their social needs as well as they maintain closer association with the older bulls to learn and gain information. However, despite of the growing evidence on the importance of male-male associations, there is a severe dearth in understanding male Asian elephant behaviour. In sexually mature males, a crucial factor governing their social behaviour is the physiological state of Musth.

Musth in Male Elephants:

Sexually mature individuals of both Asian and African male elephants undergo a phase of musth, which is associated with heightened sexual activity and testosterone levels. An elephant in musth displays unique physical, behavioural and physiological characteristics. The physical characteristics defined by swelling of the temporal gland and secretion of a hormone called temporin, along with constant dribbling of urine along the hind legs, are often used as visual cues to identify an elephant in musth (Poole et al.1981, Jainudeen et al.,1972). This kind of pattern of urine dribble has also been noticed in domestic goats along with several species of Cervidae (Struhsaker,1967, Lent,1965).

Musth in Asian and African elephants:

While musth has been extensively studied in Asian and African elephants, there are notable differences between the two species regarding the duration, frequency, and intensity of musth cycles.

In Asian Elephants, musth typically lasts 2-3 months, ranging from a few weeks to 9 months and is exclusive to post-pubertal males(Jainudeen et al.,1972a). Asian elephants can come in musth multiple times throughout the year(Sukumar,2003)

On the other hand, musth in African elephants persists for a shorter duration, and temporal gland discharges are common in both mature and immature elephants of both sexes(Poole et al,1981). An individual african male elephant may enter into musth on a yearly or biennial basis.(Poole et al.,1981)

However, unlike the periodic rutting in ungulates, musth periods in Asian and African Elephants are asynchronised and can occur throughout the year.(Poole et al.,1981, Sukumar 2003)

African elephants also have a sexually active, non-musth state in which they associate with female groups and have increased androgen levels. (Ganswindt et al.,2004).

Behavioural characteristics of musth:

(1) Heightened aggression and dominance displays:

The hypothalamic-pituitary-gonadal axis regulates musth in male elephants.(Ghosal et al.,2013). The heightened testosterone levels are linked to increased aggression, unpredictability, and dominance displays, especially towards rival males. These kinds of dominant displays facilitate an individual to establish social rank and gain access to receptive females (Gandswidt et. al,2010). An elephant may have frequent and consistent musth cycles or shorter, infrequent musth cycles depending on age and body condition. Therefore, an older male with a better body condition is more receptive to a female and has better reproductive success than a younger male or a male with a poor body condition (Chelliah et al.,2013).

(2) Mating behaviour and seeking oestrous females

It has been discovered that males in musth rely on olfactory cues to detect the presence of oestrous females in their vicinity. They may also exhibit an enhanced sense of smell during musth, allowing them to detect the pheromones released by receptive females (Poole&Granli,2011).

In African elephants(McComb et al., 2000) and Asian Elephants(DeSilva,2010), there have also been reports on using long-distance vocal cues like low-frequency rumbles and trumpets to attract potential males and announce their reproductive status to the conspecifics.

(3) Home range expansion and change in movement pattern:

Males in musth display extensive ranging behaviour and traverse large territories, often extending beyond their typical home ranges, in search of receptive females (Rasmussen&Schulte,1998; Fernando et al., 2003). This roving behaviour increases reproductive opportunities and genetic diversity by allowing the males to encounter multiple potential mates (Wittemyer et al.,2008). Moreover, when in musth, male elephants also exhibit selective foraging behaviours to optimise resource acquisition. (Sukumar et al.,2003).

Musth and spatial distribution of male Asian elephants in a landscape:

Studies on various herbivores like wildebeests(Martin et al.,2015), moose(Leblond et al.,2010) and red deer(Debeffe et al.,2019) show that the hormonal changes during the mating season trigger them to alter their movement patterns to optimise mating opportunities (Mysterud,2011; Fryxell et al., 2008). As mentioned in the previous sections, these observations hold true even for Asian elephants. Male Asian elephants in musth are also known to expand their home range in search of a female in oestrous (Chelliah et al., 2013) and spend most of their time associating with a herd (Keerthipriya et al., 2019). It has been observed that males in musth do not associate in all-male groups (Srinivasiah et.al, 2019) and non-musth males may infact be repelled by musth males as a threat avoidance strategy (Sukumar et.al, 2003). However, a study on African savannah elephants shows that males may indulge in forming strategic cooperative alliances with other males in musth to enhance their mating success (Ahlering et al. 2013).

Eventhough, these studies hint towards the effect of musth on the movement pattern and associations of male elephants, they do not give a broader idea on the effect of musth on the spatial distribution of male elephants at a population level (this could be because most these studies were conducted using direct observations and hence had limited sample size). Therefore, one of the aims of this study is to understand the effect of musth on the spatial distribution of all the male Asian elephants in the study area using the camera trap method.

The Social Complexity Theory: In relevance to Elephants

The social complexity hypothesis is based on the idea that certain species' cognitive abilities and intelligence have evolved due to the demands of living in complex social groups (Peckre et al.,2019). Animals living in complex social structures, such as primates (Bryne&Whiten, 1988), cetaceans (Connor&Mann,2006) and certain bird species (Heinrich&Bugnyar,2005), exhibit sophisticated social behaviours and communication systems. These animals face cognitive demands such as social learning, perspective-taking and problem-solving to navigate their complex social environments (Holekamp et al.,2007).

From the previous sections of this thesis, the social complexity theory can also be discussed from the context of elephants due to their substantial demands of maintaining social relationships and navigating hierarchies (McComb et al.,2001). Social complexity in elephants, reflected in matriarchal societies and intricate social bonds, is intertwined with sophisticated communication. Elephants communicate through a vast repertoire of tactile, chemical and acoustic signals to facilitate coordination, cooperation and emotional expression within individuals (Sukumar et al.,2003). Each of these communicative signals has its unique relevance in elephant societies.

I. Tactile Communication:

Tactile communication in elephants predominantly involves trunk and is crucial in fostering social bonds, conflict resolution, and emotional expression among individuals. Mothers use their trunks to nurture and protect calves, strengthening maternal bonds (Poole & Granli, 2011; Sukumar, 2003; Yasui et al.,2017). During conflicts, elephants engage in trunk intertwining and touching, promoting reconciliation and social harmony (Bates et al., 2008; Wemmer & Christen, 1987). Tactile interactions also facilitate social learning among calves, shaping their understanding of group dynamics (Poole & Granli, 2011).

II. Chemical Communication:

Chemical communication in elephants involves using pheromones and scent markings to convey reproductive status, social hierarchy, and territorial boundaries (Sukumar,2003). Male elephants release pheromones in musth, signalling their sexual state and dominance (Rasmussen et al., 2002). While less studied in Asian elephants than their African counterparts, chemical communication likely plays a vital role in their social interactions and reproductive strategies, reflecting their reliance on olfactory cues in their natural environments.

III. Vocal communication:

Due to complex social systems, acoustic signals play a vital role in African and Asian elephant societies (Stoeger & de Silva, 2014). The trunk serves as a unique feature in the vocal apparatus of the elephants, facilitating them to produce a wide range of sounds (Soltis, 2010). These calls help maintain social cohesion, coordinate group movements, express an individual's emotions (Poole,2011), and even signal reproductive states (McComb et al.,2000). Studies have also shown that elephants use vocalisations for individual recognition (Soltis et al.,2005).

The vocal repertoire of African Elephants has been extensively studied, consisting of over 30 different vocalisations, including Rumbles, Trumpets, Bellows, Growls, Snorts, Barks and several combination calls (Poole,2011). On the other hand, the vocal repertoire of their Asian counterparts, even though it hasn't been studied as extensively, predominantly consists of Rumbles, Trumpets, Roars, Barks,

combination calls and Chirps (also referred to as Squeaks, de Silva,2010)- call type unique to Asian elephants.(de Silva,2010; Nair et.al.,2009).
The type pattern of the call may be correlated to the context in which the call has been produced (Poole,1999). For example, Rumble- a low-frequency call, is often used by Asian and African elephants to convey various social, physiological and reproductive information over long distances.

Effect of anthropogenic factors on vocal communication:

Anthropogenic pressure such as habitat destruction, poaching and human-elephant conflict act as a severe challenge in conserving elephant populations worldwide. These pressures are not only a threat to the elephant population but also influence their behaviour, including vocal communication. Stress and fear-induced due to anthropogenic factors cause the elephants to modulate their vocalisations, potentially leading to changes in call frequency, duration or intensity (McComb et.al.,2014; Sharma et.al, 2019). Moreover, there has been a study showing that Asian elephants lower their rate of audible vocalisations while traversing through a human-dominated landscape (Srinivasiah et al.,2012). A study on African elephants also mentions reduced vocalisations and changes in call structure amongst the elephants habituated to human presence (Soltis et.al.,2014). Additionally, anthropogenic noise pollution is also known to affect elephant vocalisations as it masks the vocalisation and reduces the effectiveness of conveying information over longer distances (Policht et al.,2016). Understanding the impact of anthropogenic pressure on elephants’ vocal behaviour is essential to mitigate human-induced stressors and preserve natural communication patterns within elephant populations. Therefore, as the final objective of this study, we make a preliminary attempt to understand the vocal behaviour of elephants in a high human-use area.

Objectives:

1. To understand the distribution of age, body condition and musth occurrence in individual male elephants.
2. To understand associations of male elephants in terms of their spatiotemporal distribution in relation to their physiological state of musth.
3. To study the vocal repertoire of Asian elephants in high human-use areas.

Chapter 2 **Materials and Methods**

For Objective I&II:

1. Study Area

The locations for the camera trapping effort were chosen based on the long-term monitoring of elephants in the landscape in southern India since 2009 (Srinivasiah et al,2019). From the knowledge of elephant-ranging patterns, an extended study area of 10,000 sq.km was demarcated. The region was then overlaid with a grid of 1,000 cells of 10 sq. km each, using QGIS. Out of this, an area of 630 sq. km was assigned as an intensive study area due to the logistical feasibility of long-term monitoring of elephants using the camera-trap method.

The Study area comprised the Protected Areas of Bannerghatta National Park, parts of Cauvery and Cauvery North Wildlife Sanctuaries, and the Reserved Forests of Ramnagara, Bengaluru and Hosur Forest Divisions. The forested area expands over 1,500 sq. km while the vegetation comprises mainly tropical dry deciduous and scrub woodland forests with numerous riparian patches.

The elevation in these areas ranges from 250m to 1000m above the sea level, with average monthly maximum and minimum temperatures being 35°C in April and 18°C in January, respectively.

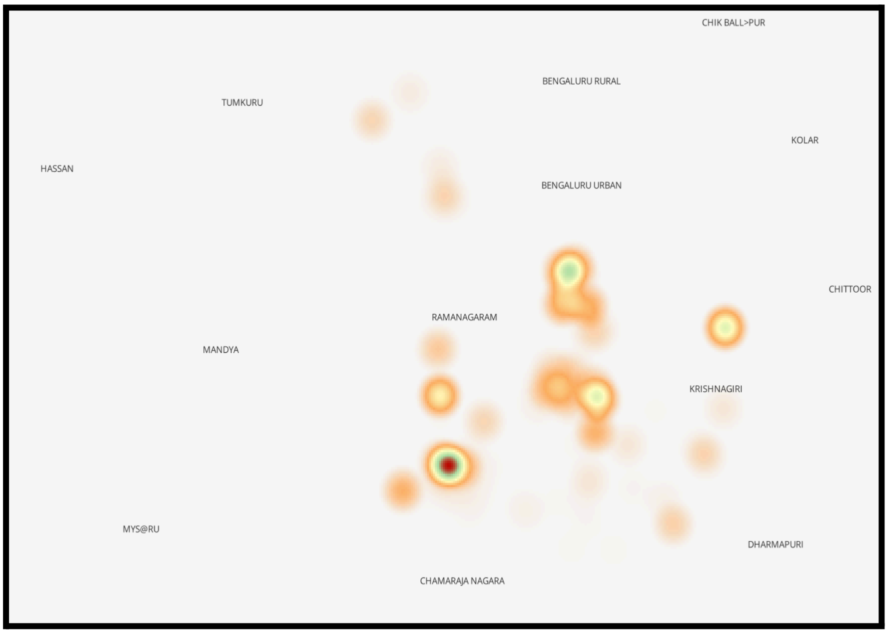


Fig 1. Distribution of elephants across our study site at different locations Cauvery Wildlife Sanctuary and Ramnagar,Tumkur and Hosur districts.

2. Collection of Photographic data:

As a longterm elephant monitoring effort using camera traps, the data was collected from February 2016 to January 2024 across different parts of Bannerghatta National Park, Cauvery and North Cauvery wildlife sanctuaries and the reserved forests of Ramnagar,Tumkur and Hosur districts of Karnataka and Tamil Nadu

One camera trap was set up per 10 sq. km grid, and an area of 150 sq. km (15 locations) was sampled simultaneously for a minimum sampling period of 15 days.

Fig 2.One of the cuddie back camera traps that were placed throughout the forest for photographic and videographic monitoring of elephants.

3. Analysis of Photographic data

For every image extracted from the camera trap. The following details about the male elephants were noted down:

i. Details regarding the location, date and time the image was recorded.

Since one of the objectives of this study involves assessing whether the physiological state affects the spatial distribution of male elephants in a landscape, the geo-coordinates of the location, along with the date and time at which the elephant was present at the location, were noted.

ii**. Classification of the male elephants based on their age and sexual maturity**

The age categorisation of the elephants was done using the relative shoulder height measures, a standard method for age estimation in wild elephants(Sukumar,2008). Using this method, the elephants were classified into SIM, SM and SSM.

Sr.no	Age Category	Age (Years)
1	Calf	0-1
2	Juvenile	1-5
3	Sub-Adult Stage-I	5-10
4	Sub-Adult Stage-II	10-15
5	Adult	>15

Table 1: Classification of elephants into different age classes

Note: The shoulder height of an adult 15-20-year-old male is comparable to a fully grown adult female. Therefore, to age categorise individuals beyond that age, other morphological features such as the extent of folding of ears, depigmentation of the ears, temporal and buccal cavity depression, extent of differentiation and prominence of domes and girth and length of tusks(in case of tusked males) were considered.

Moreover, since our study is mainly focused on the physiological state of musth, we chose to further categorise the elephants based on their sexual maturity statuses into three different categories:

Sr.no.	Abbreviation	Maturity Status	Age (Years)
1	SIM	Sexually and socially immature	0-10
2	SM	Sexually Mature	10-20
3	SSM	Sexually and Socially Mature	>20

Table 2. Classification on male elephants into different maturity classes based on their age.This categorisation was based on the 2019 study by Srinivasiah et al. on all-male groups in Asian Elephants.

Fig 3. (From left to right) A photo representing the relative shoulder heights of individuals from different age classes: A sub-adult stage-**I** individual, a calf, a juvenile, an adult female and a sub-adult stage-**II**, sexually mature male. Photo credits: Frontier Elephants program

iii. Classification of male elephants based on the presence and absence of tusks.

Since our landscape consists of many tusked and tuskless males, the elephants recorded in camera traps were categorised as tusked males(T) or tuskless males, aka Makhnas (M).

Fig 4. Image of a Tuskless/Makhna male(top) and a tusked male(bottom) recorded in the camera trap.

iv. Classification based on group categories:

For our study, a group was defined using a temporal measure. All the individuals captured within a three-hour interval from the time of first elephant record at a given location were considered to be from the same group (Srinivasiah et.al, 2019). Based on this measure, the elephants were categorised into following three groups:

Sr.no	Group Type	Description
1	Mixed-sex herd (H)	Comprising of both males and females
2	All-male groups(A)	Comprising of males only
3	Solitary(S)	Single male elephant

Table 3. Classification of elephants based on their group type depending on the composition of the group.

Fig 5. Image of a Solitary male elephant (Top Left), an all-male group (Top Right) and a mixed sex herd captured on camera trap.
Photo credits: Frontier Elephants Program

v. Classification based on the body condition:

Each elephant recorded on the camera trap was scored from I to V based on his body condition. These scores were allocated depending on the body fat deposition patterns around the pelvis, ribs and backbone and depressions around the pelvic and lumbar regions. (Pokharel et al., 2017)

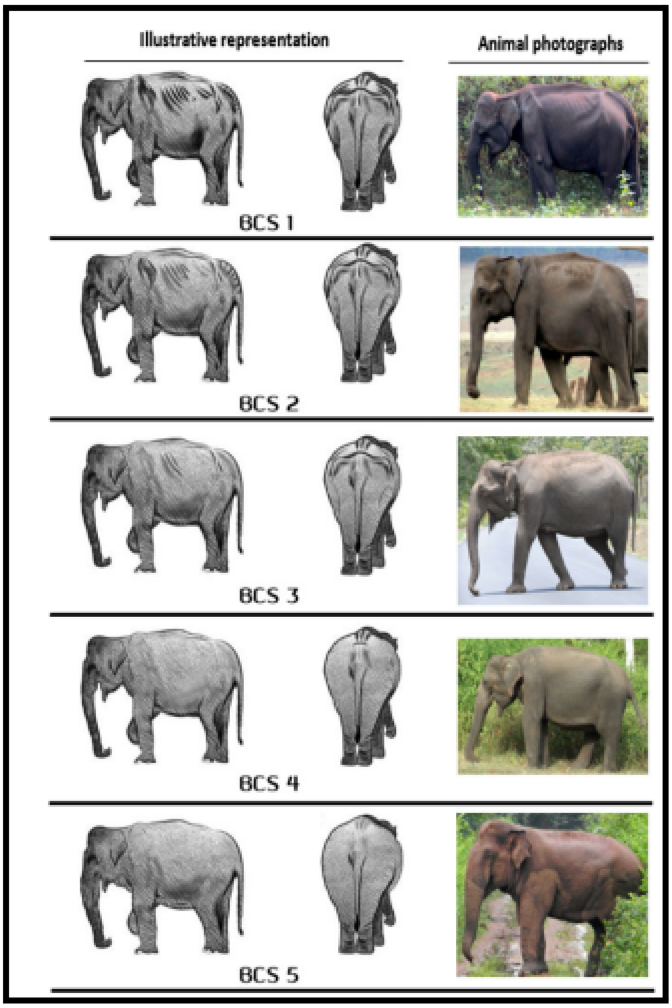


Fig 6. Representative schematic and photographic illustrations of elephants showing their body condition.

Schematic credits: Pokhrael et al., 2017

vi. Classification based on the Musth status:

Elephants were categorised into two categories based on the presence or absence of musth. The secretion of temporin from the temporal gland and constant urine dribbling over the hind legs were used as visual cues to identify an elephant in musth.

Fig 7. Image of a Sexually and socially mature bull elephant in musth recorded in our camera trap. Prominent secretion from the temporal gland can be observed along with a faint urine dribble along the hind legs.

Photo credits: Frontier Elephants Program

vii. Identification of Individuals:

As a part of the long-term monitoring of elephants in the landscape, most individual male elephants have been identified and given a unique ID. For each individual identified, we note over 114 morphological features on top of the unique characteristics (for eg, cuts, wounds, deformities, body marks, etc.) possessed by the individual.

Specific to Objective I :

1. Creating a table to understand musth occurrence in the male elephants recorded in the study area:

I. From the data collected during February 2016 to January 2024, we recorded a total of 3548 instances where male elephants were in front of the camera traps with an average of 433 images per year. From this dataset of 3548 images, we identified 47 individuals, who were recorded in musth at multiple instances for a particular period.

II. Based on the information received from camera trap images we created a table containing the details of the months where each elephant was photographed in musth. Since our study involves assessing the effect of musth on spatial distribution, it was also important to get information about the months in which the same individual was not in musth. Out of the 47 individuals, only 43 were recorded in and out of musth. Therefore, only these individuals were considered for our further study.

2. Plotting the frequency distribution of the selected 47 individuals based on their maturity status.

After identifying the 47 individuals that were recorded in and out of musth on our camera traps, we then categorised them based on their maturity classes and plotted a histogram using the software R, version 4.2.1 to see visualise the trend in the distribution.

3. Plotting the frequency distribution of the selected 47 individuals based on their body condition scores.

After identifying the 47 individuals that were recorded in and out of musth on our camera traps, we considered the different time points at which they were recorded in musth and not in musth and noted down the body condition score for the individual for that particular record. We then categorised these individuals based on the different body condition scores they were recorded in and then plotted a histogram using the software R, version 4.2.1, to visualise the trend in the distribution.

Specific to Objective II:

As mentioned above, based on the information received from camera trap images we created a table containing the details of the months where each elephant was photographed in musth.Since our study involves assessing the effect of musth on spatial distribution, it was also important to get information about the months in which the same individual was recorded to not be in musth. Out of the 47 individuals, only 43 were recorded both in and out of musth. Therefore, only these individuals were considered for our further study.

1. Computing the distance between the bull of interest and all the other bulls in the vicinity using QGIS

I. Based on the musth occurrence table and details collected from the camera trap images, we randomly chose one date for each individual when he was recorded while in Musth and not in Musth. While analysing the image data, we also included the details regarding each location's GPS coordinates.

II. For the next step, we considered a time interval of 31 days- 15 days before and after from the selected date and made a note of all the bull elephants recorded in that area, along with the GPS coordinates of the location in which they were found.

III. All these distances were then added to an Excel sheet, and the Distance Matrix function in QGIS (version 3.34.2) was used to compute the distance between all the bull elephants from the individual of interest when he was in musth and when he wasn't in musth.

2. Computing the median of the distances and using a permutation test to check the statistical significance of the difference.

I. After computing the distances, we calculated the median for distances when the bull was in and out of musth. We then compared the two medians and computed box plots to visualise the trends.

II. We then performed a permutation test using R, version 4.2.1, to compute P-values and check the statistical significance between the differences.

III. The code conducts a permutation test to compare median distances between elephants in Musth and those not in Musth. It sets the sample size and number of permutations and then creates permuted samples by shuffling distances randomly. It ensures each distance is used only once. Comparing the difference in median distances from the permuted samples to the observed difference assesses how likely the observed difference is due to chance. This process helps determine whether the observed difference is significant or could have occurred randomly.

4. For Objective III:

1. Passive Acoustic monitoring using audio recorders

Based on the long-term elephant monitoring data in our study area, we identified a single location inside the Cauvery Wildlife Sanctuary as a high human-use area that could facilitate the passive acoustic monitoring of elephants. We used the Songmeter by Wildlife Acoustics (omnidirectional; frequency response, 4Hz) and an acoustic recorder by BanderLog Pvt.Ltd (frequency response,12Hz, Fig 8) for acquiring acoustic data at a sampling frequency of 48 kHz. The acoustic recorder was set up along a water hole, and data was continuously sampled from November 2023 to January 2024, yielding 1176 hours of audio data.

Fig.8 Image of an acoustic recorder by BanderLog Pvt. Ltd. set up along a waterhole at a high-human use area inside Cauvery Wildlife Sanctuary.

2. Elephant vocalisations extracted from the camera traps:
Within the duration of this thesis (May 2023-March 2024), vocalisations recorded in the camera traps placed at different locations (same as those used for study Objectives 1 &2) were also considered for the study.

3. Analysis of Acoustic Data:

This study was conducted among free-ranging populations in a high human-use area. The analysis for this study objective would be majorly descriptive, and it's a preliminary attempt to assess the acoustic behaviour of elephants in our study area. The acoustic data was collected as individual, hour-long files for 1176 hours.

3.1 Detection of Elephant activity:

We used Raven Pro 1.6.5 to visualise and create spectrograms of the recorded data. On going through multiple files, we observed that since the acoustic recorder was placed next to a waterhole, the elephant movement in water appeared as dark vertical smears on the spectrogram. Moreover, we classified certain sounds as non-intentional : Airbursts, Nasal-blow, breaking of branches, snorting, farting and dung-dropping. Therefore, these two factors were used to detect the presence of elephants in the location. It is important to note that we define intentional and non-intentional calls or sounds based on the intention to communicate with other conspecifics or a reaction to individuals of different species.

3.2 Detection of Elephant vocalisation and classification of call type:

We used studies by Nair et al., 2009 and de Silva, 2010 as a reference to detect, define different types of calls and construct vocal repertoire of elephants in our study area.

3.3 Measurement of call features:
We used the Raven Pro 1.6.5 software to analyse the call features. Each files were manually examined. Once the elephants' sounds were detected, a box was drawn around the calls of interest. Later, boxes were precisely cut to extract the acoustic properties of the calls such as call duration, central frequency, central time, peak frequency, peak time, delta frequency, delta time and maximum frequency. Because of the limitation in the software, we could not measure the fundamental frequencies

of the calls. In the case of combination calls, for example, roar-rumbles, roars and rumbles were analysed separately (de Silva 2010). Since chirps consist of multiple units in a single bout, each unit was analysed separately, and the values for all the units were averaged to get the final measurements.

Chapter 3 **Results**

5. A. Understanding the distribution of individuals recorded in musth based on their maturity class.

In order to understand the distribution of individuals recorded in musth(N=47), in terms of their maturity class, we plotted a histogram. It can be observed from the figure below that out of the 47 individuals recorded in musth, 27 belonged to the maturity class SSM (Sexually and Socially Mature), 20 belonged to the maturity class SM(Sexually Mature) and none of the individuals belonged to the maturity class SIM (Sexually Immature).

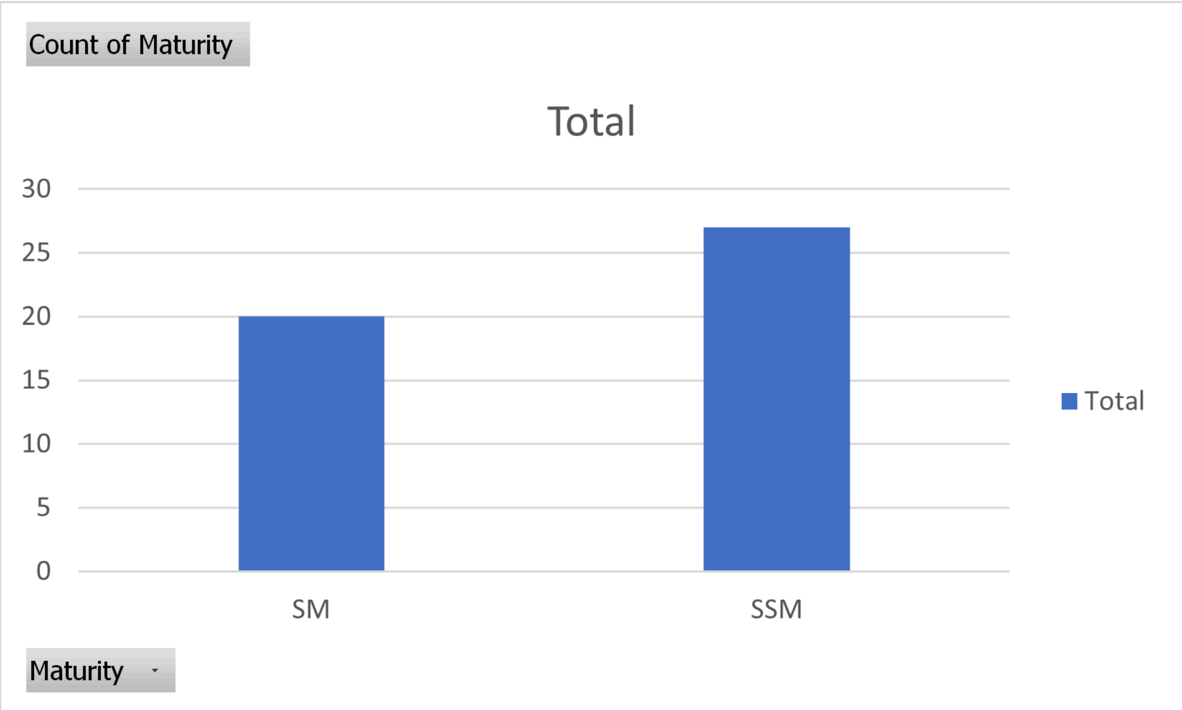
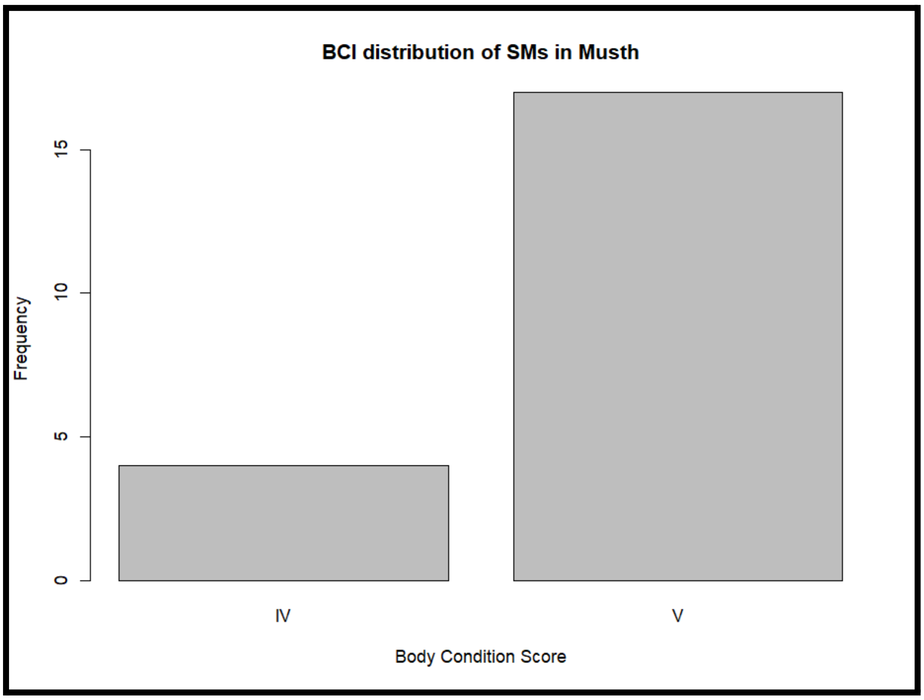


Fig9: The figure shows the frequency of individuals selected for the study recorded in camera traps based on their maturity classes.

B. Understanding the distribution of individuals recorded in musth based on their body condition.

On plotting the frequency distribution of body condition scores of individuals when they were in and out of musth, we observe that for both SMs and SSMs the body condition scores remain constant, with a few number of individuals with a lower score when they are out of musth.



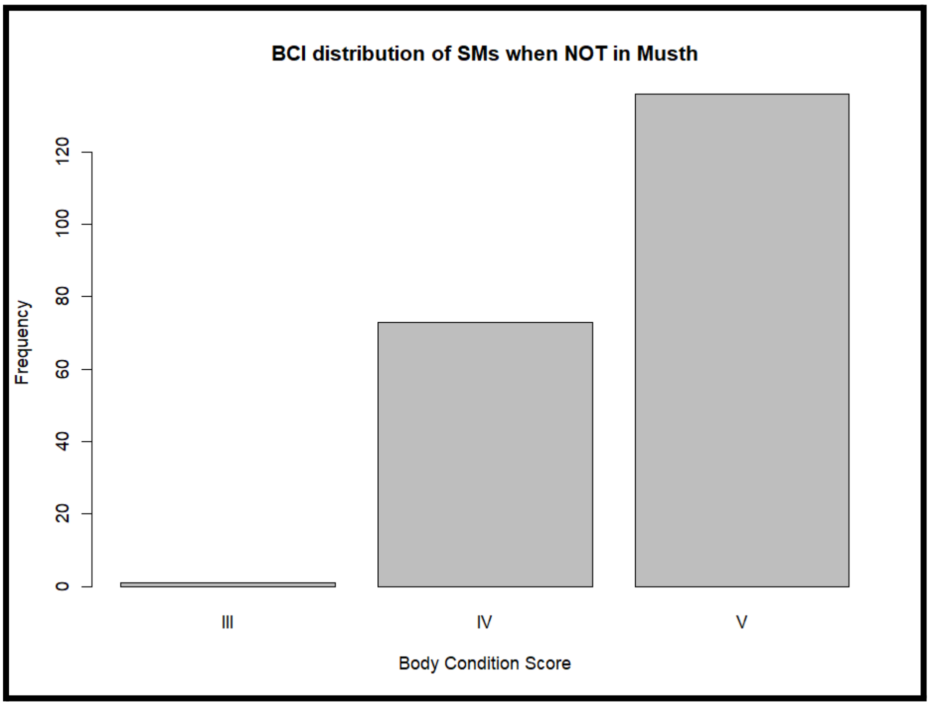
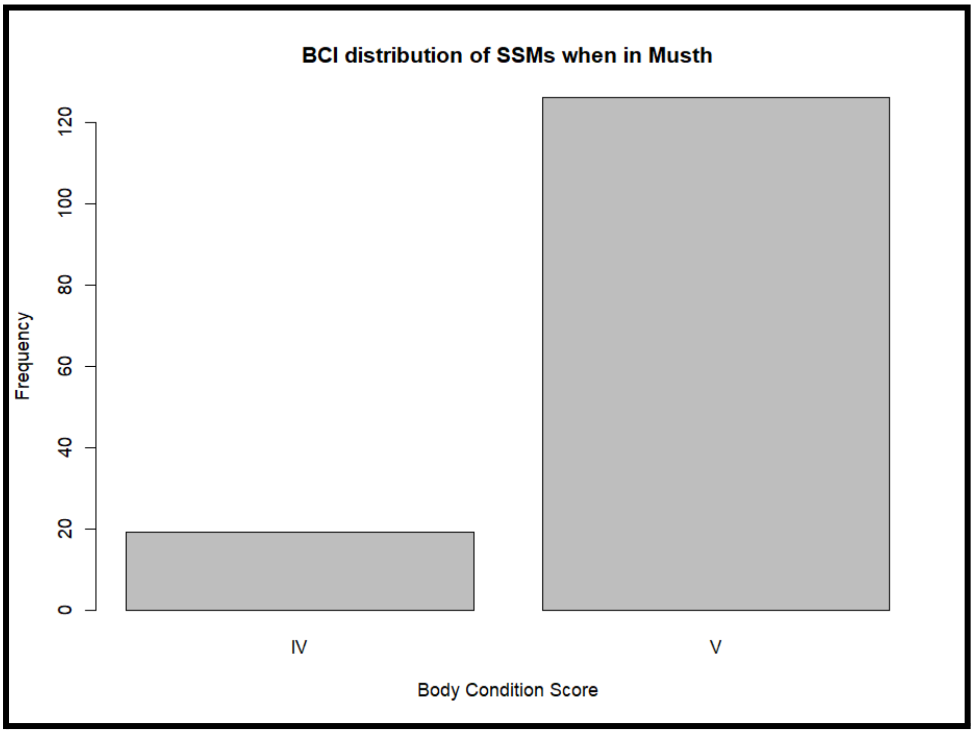


Fig10 The above figure shows the difference in the body condition of SM individuals when they are in(top) and out(bottom) of musth.



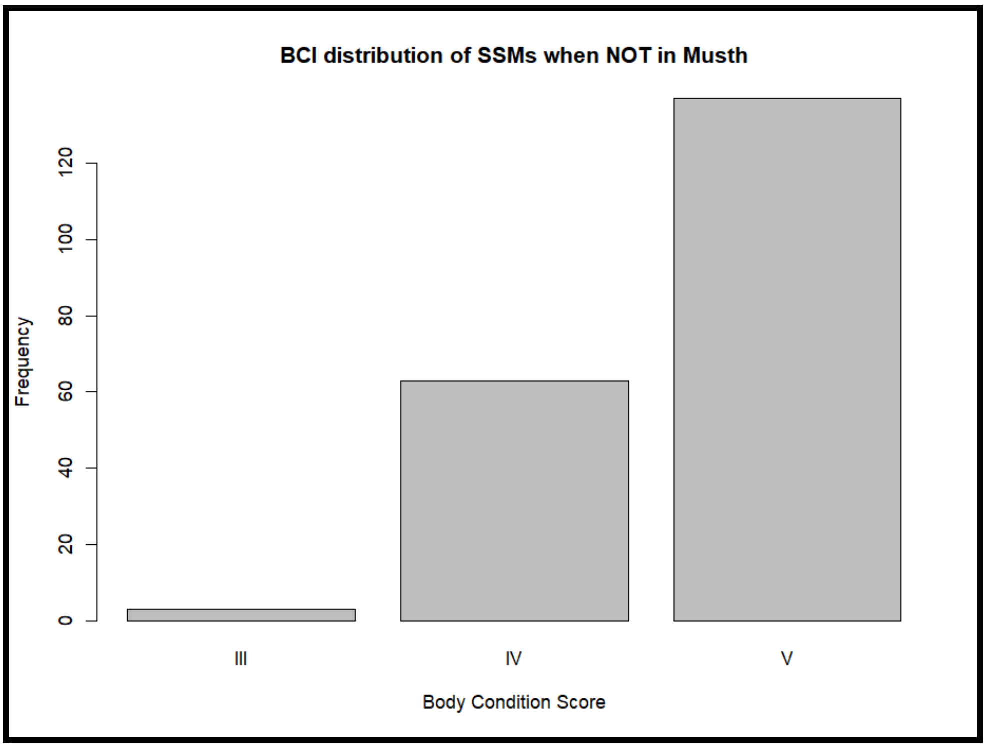


Fig 11.: The above figure shows the difference in the body condition of SSM individuals when they are in(top) and out(bottom) of musth.

C. Understanding the distribution of Musth occurrence in the individual males:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	AIR			A	A	A	A	A		A	A		
2	ALA	NA	A		NA	NA	A	NA	NA	NA	A	A	NA
3	BB1	A	A		A	A	A	A	A	A	A	A	A
4	BHE	A	A	A		NA		A	A		NA	A	A
5	BID	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA
6	BIT	A	NA	NA	NA	A		NA	NA	NA	NA	NA	NA
7	BLU	NA	NA			A		A	A	NA	NA	NA	NA
8	BUL	A	A		A	A	A		A	A	A	A	A
9	DAE	A	A						A	A		A	A
10	ELE	NA	NA	NA	NA		A	A	A	NA	NA	NA	NA
11	GIR		NA		NA	NA	NA	NA	NA	NA	A	A	NA
12	HIR	A	A	A							A	A	A
13	JRM	NA	NA	NA	A	A		A	NA	A	A	NA	A
14	KAB	NA	NA	NA					A	A	A	A	A
15	KAG	NA		NA	NA	A	A	A	A	A	NA	NA	NA
16	LON	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA
17	MAK	A	A	A	A						A	A	A
18	MAR	NA	NA	A	NA	NA	NA	NA	A			A	NA
19	PAL					A	A	A	A	NA	NA	NA	NA
20	PAT	NA	A	A	A	A	A	NA		A	A	A	
21	POI	A	NA		NA	NA	NA	A		A	A	A	A
22	PTJ		A	A	A	A	A	A	A	A	A		A
23	RIG	NA	NA	NA	NA		NA				A	NA	NA
24	SAM			A	A	NA	NA	NA	NA	NA	NA	NA	NA
25	SAT	NA	NA	A	NA	NA	A	A		NA	NA	NA	A
26	SHO	A	NA	NA	A	A	A	NA	A	A	A		NA
27	SHM	NA	NA	NA	NA		NA	NA	NA	A		NA	NA
28	TIN	A	A		A	A	A	A	A	A	A	A	A
29	VAA	NA	NA	NA	A	NA	A		A	NA	NA	NA	NA
30	VAN	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
31	VEN			A	A	A	A	A	NA		NA		
32	YAS	NA	NA	NA	A		NA	NA	NA	NA	NA	NA	NA
33	GOJ	A	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA
34	BOP	NA	NA	NA	NA	NA	NA		NA	NA	A	NA	NA
35	NEX	NA	NA	NA	NA	NA	NA	NA		NA	NA	NA	A
36	MUS	NA	NA	NA	NA	NA			NA	NA	A	A	NA
37	TOP	NA	NA	NA	NA	A	NA		A	NA	NA	NA	NA
38	DUM	NA	NA	NA	NA	NA		NA	NA	A	NA	NA	NA
39	BOL	NA	NA	NA	NA	NA	NA	NA	NA		NA	A	A
40	JOE	NA	NA	NA	A	NA	NA	A			NA	NA	A
41	DUK	NA			NA	NA	NA	NA	NA	NA	NA	NA	NA
42	CHI	NA	NA	NA	NA				NA	NA	NA	NA	A
43	WRI	NA	NA	A	A			NA	NA	NA	NA	NA	NA
44	FAL	NA	NA	NA	A	NA		A	NA	A	NA	NA	NA
45	SAB	NA		A	A	NA	NA	NA	NA	NA	NA	NA	NA
46	WON	NA	NA	NA	NA	NA	NA			A	NA	NA	NA
47	SUJ		NA	NA	NA	NA	NA			NA	NA	NA	

Table4. The table shows the month-wise distribution of the 47 bulls observed to be in musth. The cells highlighted in black are the months in which the individual was recorded in musth. The cells highlighted in pastel red and labelled “A” are the months in which the individual was recorded out of musth/musth was absent. The cells labelled “NA” are the months for which the data was unavailable for the particular individual. The first column represents a three-letter code given to each individual based on his ID.

a. On creating a table containing the month-wise distribution of musth occurrence in the 47 bulls of our interest, we observed that for 8 bulls out of 47, we had their musth occurrence data for all 12 months of the year. Out of these 8 bulls, 4 individuals belonged to the maturity class SM and 4 belonged to the maturity class SSM. For 3/47 bulls we had musth occurrence data for 10 months, out of which 2 belonged to the maturity class SM, and 1 belonged to the maturity class SSM. For the rest of the 36 bulls, the data availability for musth-occurrence ranged from 9 months to 1 month.

b. The highest continuous musth period observed in a bull is 6 months (For individuals tagged as HIR and DAE), and the second highest is 5 months for four individuals. It is important to note that all these six individuals belong to the maturity class SSM.
c. It may be noticed that SM individuals have staggered and asynchronous musth periods as opposed to SSM individuals, who seem to have long and continuous musth periods.

Objective II: Understanding the effect of musth on the spatial distribution of male elephants in our study area.

To estimate the spatial distribution of individuals in our study area, we calculated the distance of a particular individual in Musth to all other individuals recorded within the 31-day time interval and compared that to the distance of the same individual not in Musth to all the other bulls recorded for that time interval.

The following were our hypotheses for our study:

H_1:Distance of Bull in musth to other bulls>Distance of Bull not in musth to other bulls

(As a threat avoidance strategy to prevent aggressive interactions and dominance displays from other musth bulls)

H_2: Distance of Bull in musth to other bulls<Distance of Bull not in musth to the other bulls.

Mating strategy: since all the females in the study area would be congregated within a particular area inside the forest, all the musth bulls would attempt to associate with the female and therefore, the inter-bull distance between two musth bulls would be less)

H_3: Distance of Bull in musth to other bulls>Distance of Bull not in musth to the other bulls.

Foraging strategy: A bull with a better body condition is likely to come into musth more frequently than a bull with a poor body condition and, therefore, have greater reproductive success. It has been observed that male individuals often associate with all-male groups while traversing through human-dominated landscapes as a high-risk, high-gain strategy to feed on crops. Moreover, it has also been observed that an all-male group does not consist of males in musth(Srinivasiah et al. 2019). We thus hypothesise that, when not in musth, the inter-bull distance between two individuals would be less.

Result I: Comparing the distances across different maturity classes

Since the physiological state of Musth is highly correlated with the sexual maturity of the individual (Sukumar,2003; Poole, 1998), we compared the distances of our selected SM and SSM individuals to the other SIM individuals or herds, SM and SSM males in the study area.

1.1 Distance of the SM and SSM individuals selected for our study to all the mixed-sex herds in the area.

The distance of both SM and SSM from the herds in the vicinity was observed to be less when the respective SM and SSM bulls were in musth as opposed to when they were not in Musth. The distance difference for both SM and SSM individuals was statistically significant with P<0.001.

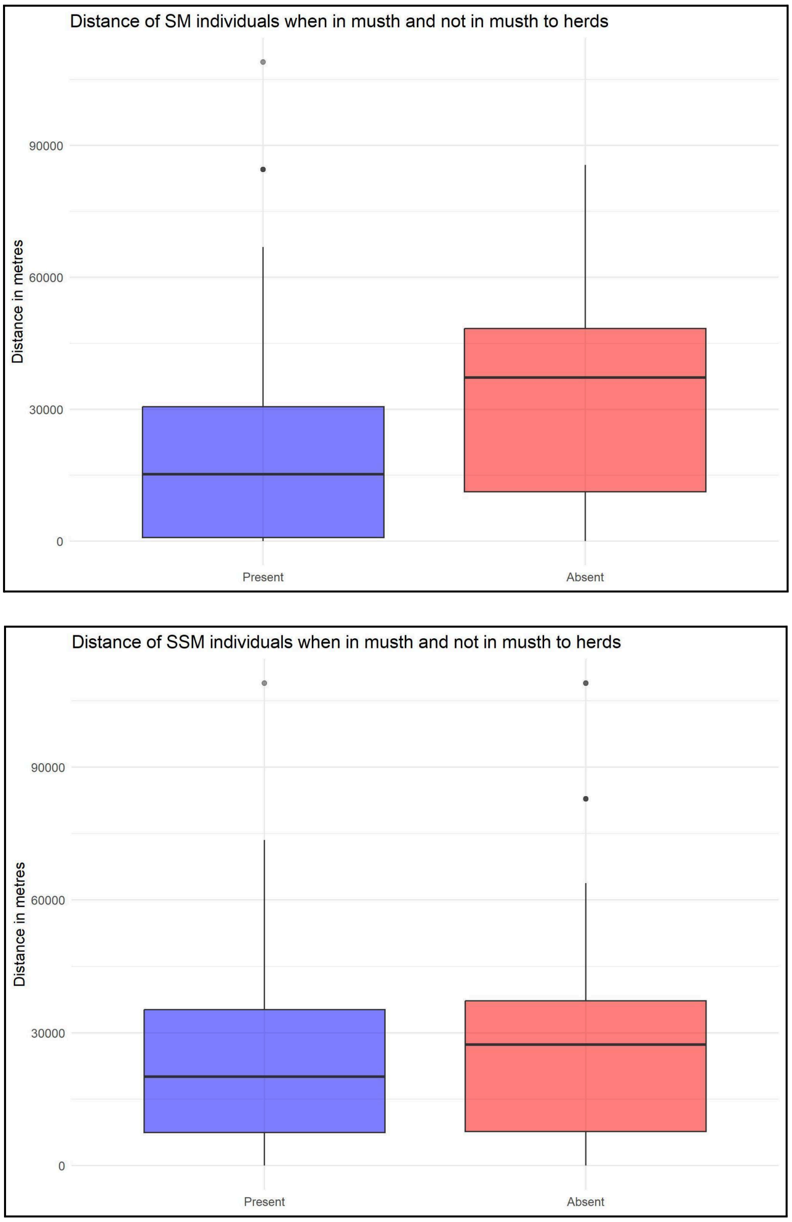


Fig12. The above figure shows the distance of our selected SM(Top) and SSM(Left) bulls in Musth to all the herds in the study area. The boxplot highlighted in blue represents the distances when the musth is present, while the one in red is representative of the distances when the musth is absent.

1.2 Distance of our selected SM and SSM individuals when in and out of musth to the distance of other SM and SSM bulls in the vicinity when in and out of musth.

1.2.1 Distance of our selected SM individuals when in and out of Musth to other SM individuals in Musth and not in musth

On comparing the distance of our SM individuals(N=18) to all other SM individuals in the study area in Musth, we observed that the inter-bull distances between two SM individuals are less when both of them are in Musth as compared to when one of them is not in Musth. However, the difference between the two is statistically insignificant with P=0.352. On comparing the distance of our SM individuals(N=18) to all other SM individuals in the study area that are not in musth. we observed that the inter-bull distances between two SM individuals are less when one of them is in Musth as compared to when both of them are not in musth. The difference between the distances is statistically significant, with $P<0.001$.

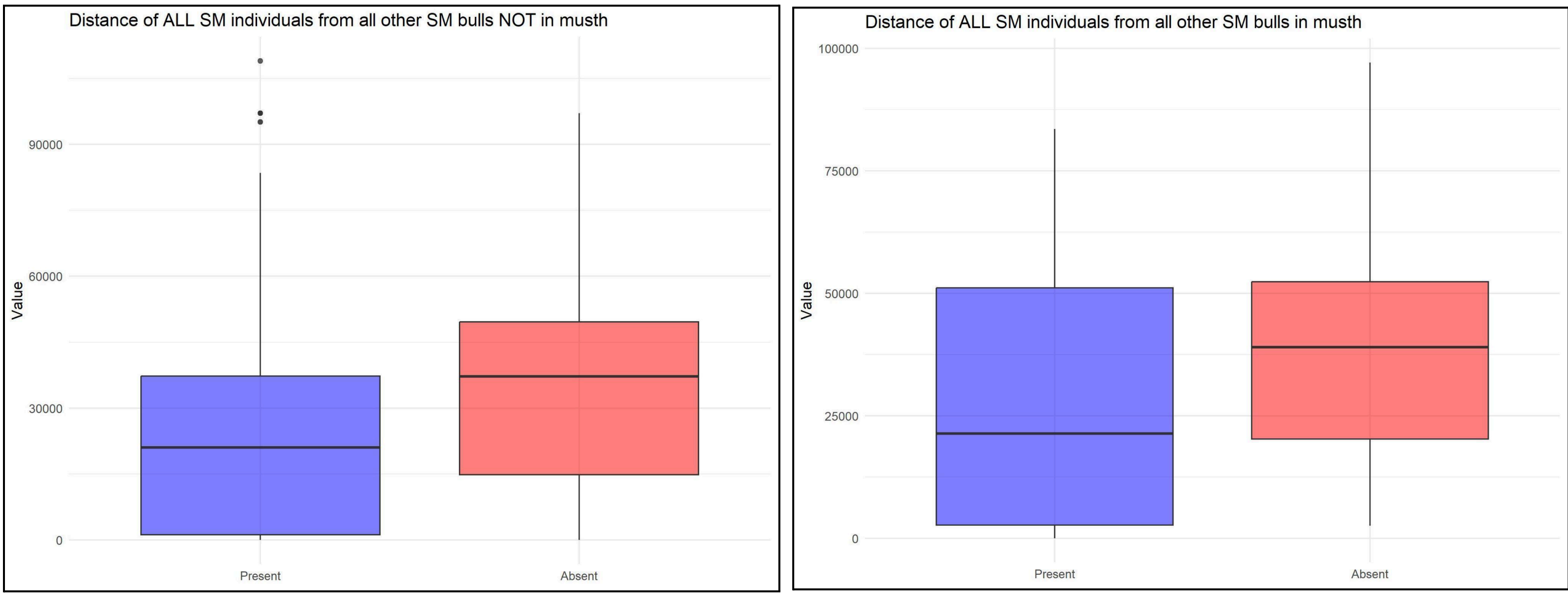


Fig13. The above figure shows the distance of our selected SM bulls in Musth(blue) and not in Musth (red) to all other SM bulls in the study area who are not in Musth (left) and in Musth (right).

1.2.3 Distance between our selected SM individuals when in and out of Musth to other SSM individuals in Musth and not in Musth

On comparing the distance of our SM individuals(N=18) to all other SSM individuals in the study area in Musth. We observed that the inter-bull distance between an SM

and an SSM bull is less when both are in musth, as opposed to when the SM bull is not. The difference between the distances is statistically significant, with P<0.001.
On the other hand, when we compared the distance between the selected SM individuals to all other SSM individuals in the study area, not in Musth, we observed that the distance between the bulls is less when the SM bull is in Musth as compared to when both the bulls are not in musth. The difference between the distances is statistically significant, with P<0.001

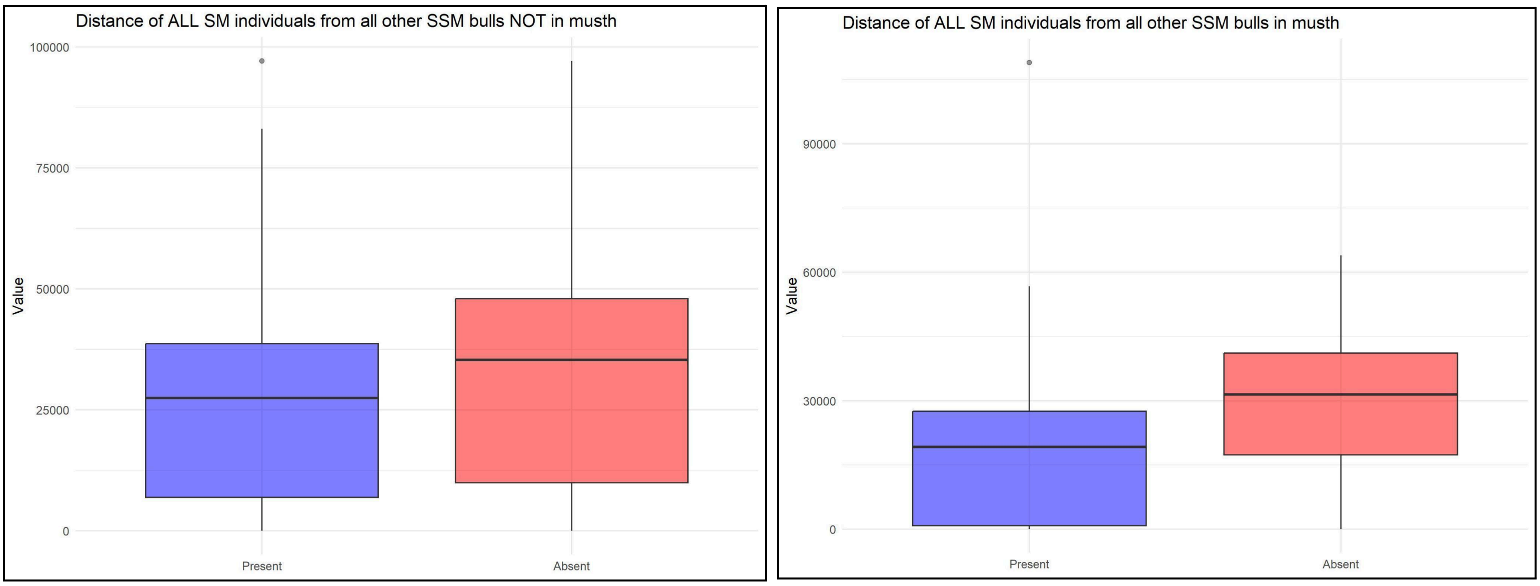


Fig14. The above figure shows the distance of our selected SM bulls in Musth(blue) and not in Musth (red) to all other SSM bulls in the study area who are not in Musth (left) and in Musth (right).

1.2.4 Distance between our selected SSM individuals when in and out of Musth to other SM individuals in Musth and not in Musth

On comparing the distance of the selected SSM individuals(N=25) to all other SM individuals in the study area in Musth, we observed that the distance between the SSM and SM individuals in less when both the individuals are in musth, as compared to the distance when the SSM bull is not in musth. However, the distance between the bulls is greater when the SSM bull is in Musth, and the SM bull is not in musth as compared to when both the bulls are not in Musth. Even though we see a pattern in the difference of the distances, both differences are statistically insignificant, with P=0.364 and P=0.268.

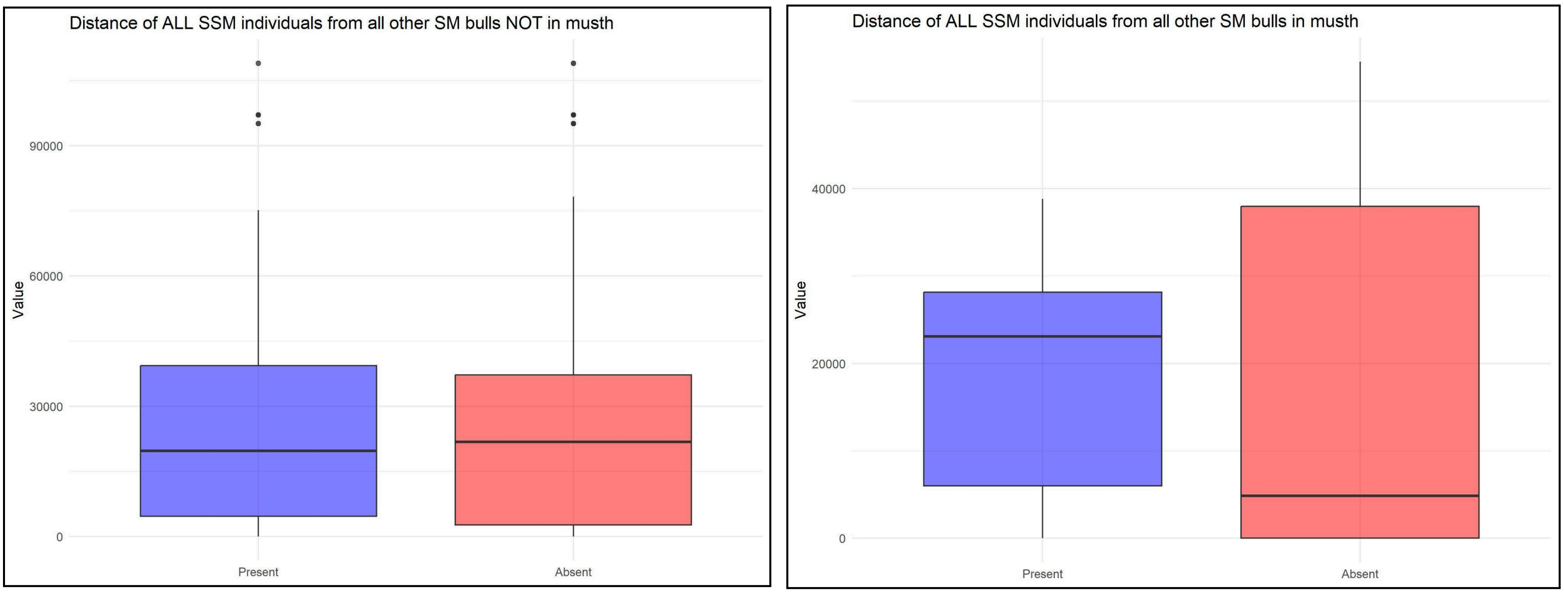


Fig15. The above figure shows the distance of our selected SSM bulls in Musth(blue) and not in Musth (red) to all other SM bulls in the study area who are not in Musth (left) and in Musth (right).

1.2.5 Distance between our selected SSM individuals when in and out of Musth to other SM individuals in Musth and not in Musth

On comparing the distance of the selected SSM individuals(N=25) to all other SM individuals in the study area in Musth, we observed that the distance between the individuals in less when both the individuals are in Musth, as compared the distance when the SSM bull is not in musth. The same holds for the distances between the bulls when one is not in musth. Even though we see a pattern in the difference of the distances, both differences are statistically insignificant, with P=0.501 and P=0.09.

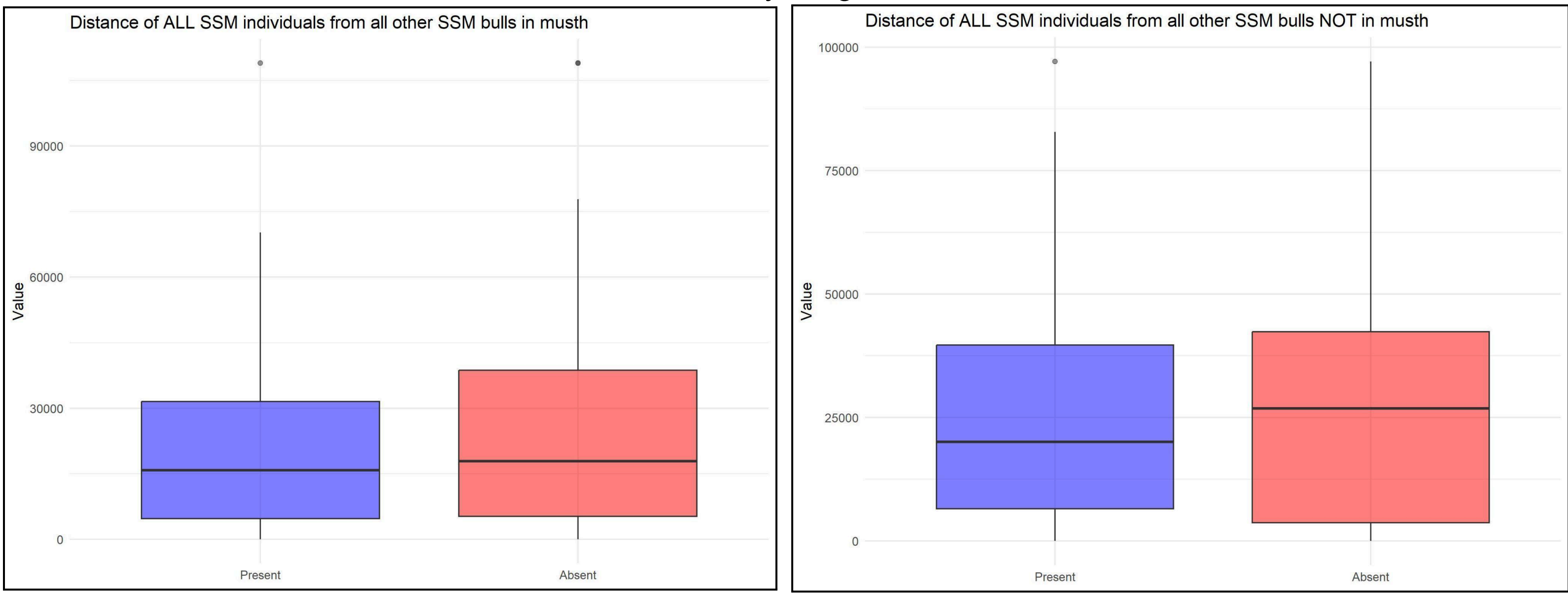


Fig16. The above figure shows the distance of our selected SSM bulls in Musth(blue) and not in Musth (red) to all other SSM bulls in the study area who are not in Musth (left) and in Musth (right).

Result 2: Comparing the distances of individuals of all-male groups when in and out of musth.

As the next step of our analysis, we identified three all-male groups in Tumkur, Hosur, and Ramnagara, which are parts of Karnataka and Tamil Nadu. We got the data regarding the group membership of each group from the previously done social-network studies. We identified three individuals from each group and calculated their distance from the other SIM individuals or herds in the study area when they were in and out of Musth. At the same time, we also calculated the distance of those same individuals from the members of their respective bull groups when they were in and out of musth. We could see that for all 9 individuals, the distance from the SIM bulls or herds was much less when these individuals were in musth. On the other hand, in the absence of musth, the individuals associate closely with the members of their respective bull groups.

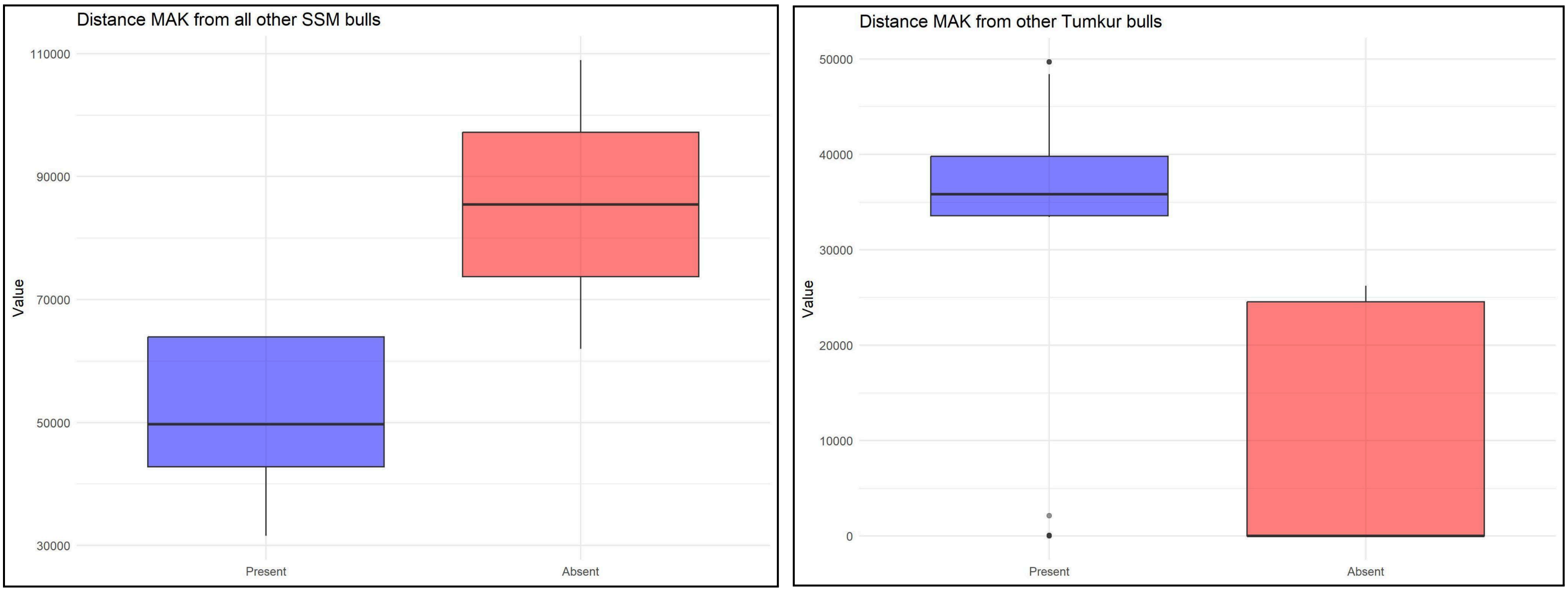


Fig17. The above figure shows the distance of our selected bull MAK from the Tumkur bull group of our study site from all the other SIM individuals in the study area(left) and the individuals from his bull group(Right) when MAK is in Musth(blue) and when he is not in Musth (red).

Result 3: Comparing the distances at the individual level

As the final step of our analysis, we individually calculated the distance between our selected individuals when in and out of musth to all the other bulls recorded in the study area. Following are the trends that we observed:

For,

i. In 17/43 individuals, the distance between the bulls was more when the individual was in musth. Of these 17 bulls, 9 belonged to the maturity class SM and 8 to the maturity class SSM.

ii. In 24/43 individuals, the distance between the bulls was less when the individual was in musth. Of these 24 bulls, 8 belonged to the maturity class SM and 16 to the maturity class SSM.

Of these 43 bulls, the difference for 23 individuals was statistically significant, with $P<0.05$.

Part B. Acoustic analysis:

Result 1: **Different types of calls recorded in our study area along with the number of times each call was recorded.**

Similar to previous studies, elephants in the study area produce at four mutually exclusive calls, a combination call type and a non-vocal sound. They are-

1. Trumpets: Trumpets are characteristic proboscidean vocalisations produced by both Asian and African species (de Silva,2010). They are loud, resonant calls produced by the forceful expulsion of air through the trunk. These calls are characterised by high amplitude and are often produced in the context of excitement, response to threat, aggression and assertion of dominance. (Nair et al.,2009). From the vocalisations recorded in our camera trap data, trumpets were produced in response to fear(juvenile male reacting to thunder), display of aggression towards conspecific(female directing the trumpet towards an adult bull to secure the calf) , display of aggression towards other species(adolescent male trumpeting at peacocks), and display of annoyance(adolescent male trumpeting and running inside the forest from the waterhole). Trumpets show higher harmonicity relative to other high-frequency calls like roars and chirps.

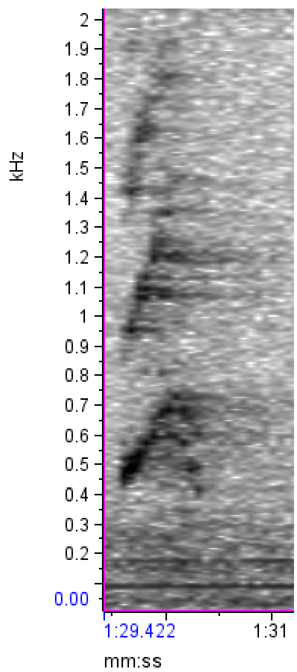


Fig18. Spectrogram of a trumpet recorded at our study site created using Raven Pro 1.6.5 software.

2. Roars: Roars are noisy, long calls with a similar frequency range as a trumpet. Roars are relatively less-harmonic than trumpets and have no specific temporal structure. Roars are produced in the context of aggression, response to threat and arousal. (Nair et al. 2009, de Silva,2010).In the camera trap recordings at our study site, roars were mainly produced to display aggression towards other species (elephant roaring in the presence of a sambar deer).

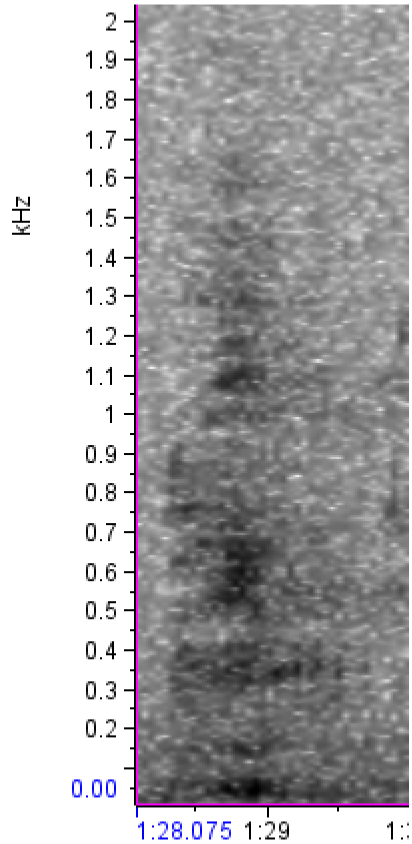


Fig 19. Spectrogram of a roar recorded at our study site created using the Raven Pro 1.6.5 software.

3. Chirps: Chirps (also referred to as squeaks-de Silva et al.,2010) are unique to Asian elephants and have a frequency range comparable to trumpets and roars. However, this call type significantly differs from trumpets and roars in terms of its characteristic temporal and spectral structure. Chirps are often produced in bouts (ranging from 1 to 8) over short durations, with frequency peaking over a narrow range. These are higher-pitched vocalisations produced in the context of annoyance, disturbance, aggression and arousal. (Nair et al., 2009; de Silva, 2010). In the camera trap recordings at our study site, chirps were mainly produced as a display of annoyance(a young male producing chirps, followed by a trumpet and charge towards the camera trap).

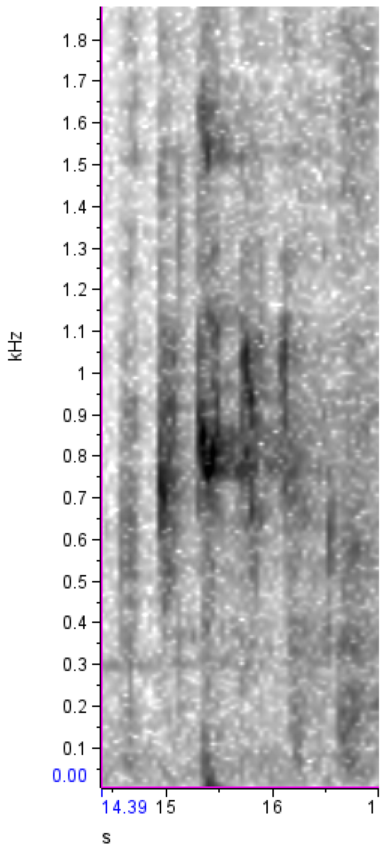


Fig 20. Spectogram of a chirp recorded at our study site created using the Raven Pro 1.6.5 software. This call was produced as a single bout of 6 units visible as vertical smears on the spectrogram.

4. Rumbles: Rumbles are the most versatile vocalisations produced by Asian elephants and do not show an overlap with any other call type in terms of their frequency. They are low-frequency sounds that vary in duration, and frequency modulation. They have a very distinct harmonic structure and are also much longer in duration. Rumbles are produced when transmitting signals over long distances to maintain social bonds, coordinate group movement, and express excitement or distress. In our study site, the rumbles were recorded only on the acoustic recorder, and there was no visible context for the same on the camera trap recording (Nair et al., 2009; de Silva, 2010).

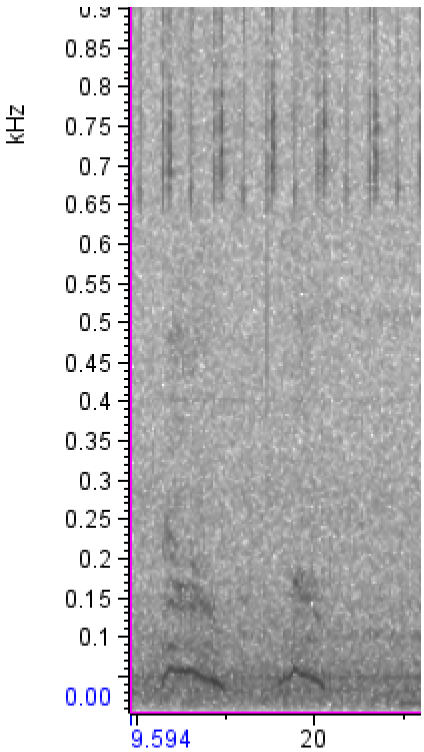


Fig 21. Spectrogram of two consecutive rumbles recorded at our study site and created using Raven Pro 1.6.5 software.

5. Roar-rumbles: Combination calls are often composed of distinct components. Each component appears to be acoustically similar to calls that occur individually. These types of calls are known to be produced in the context of movement and searching and were also found to be produced by calves wanting to be nursed (de Silva, 2010). At our study site, this call type was produced as a display of aggression and annoyance towards another species (A female elephant produced three roar-rumbles directed towards a sambar deer in the vicinity).

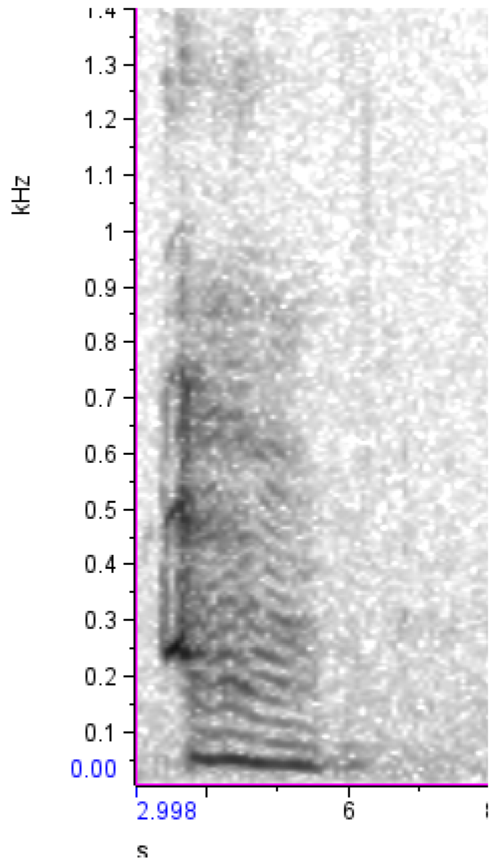


Fig 22. Spectrogram of a roar-rumble recorded at out study area , created using the Raven Pro version 1.6.5 software.

6. Barks: Barks are short calls and a-periodic in nature. They are spontaneous vocalisations produced in the context of group movement and aggression and are mostly directed towards conspecifics (Nair et al., 2009; de Silva, 2010).In our study site, barks were recorded only on the acoustic recorder, and there was no visible context for the same on the camera trap recording.

Out of the 1176 files of audio data, we could detect elephant activity in 124 files from which 160 calls were detectded. Out of these 160, only 109 calls were analysable. Since this is a high human-use area, the rest of the 48 calls overlapped with non-elephant sounds. Moreover, we also considered the 38 calls recorded on the camera traps for this part of the analysis.
Out of all the calls recorded, trumpets were the highest in number. We recorded 62 trumpets. On the other hand, barks were the lowest. We had only three recordings of this call type.

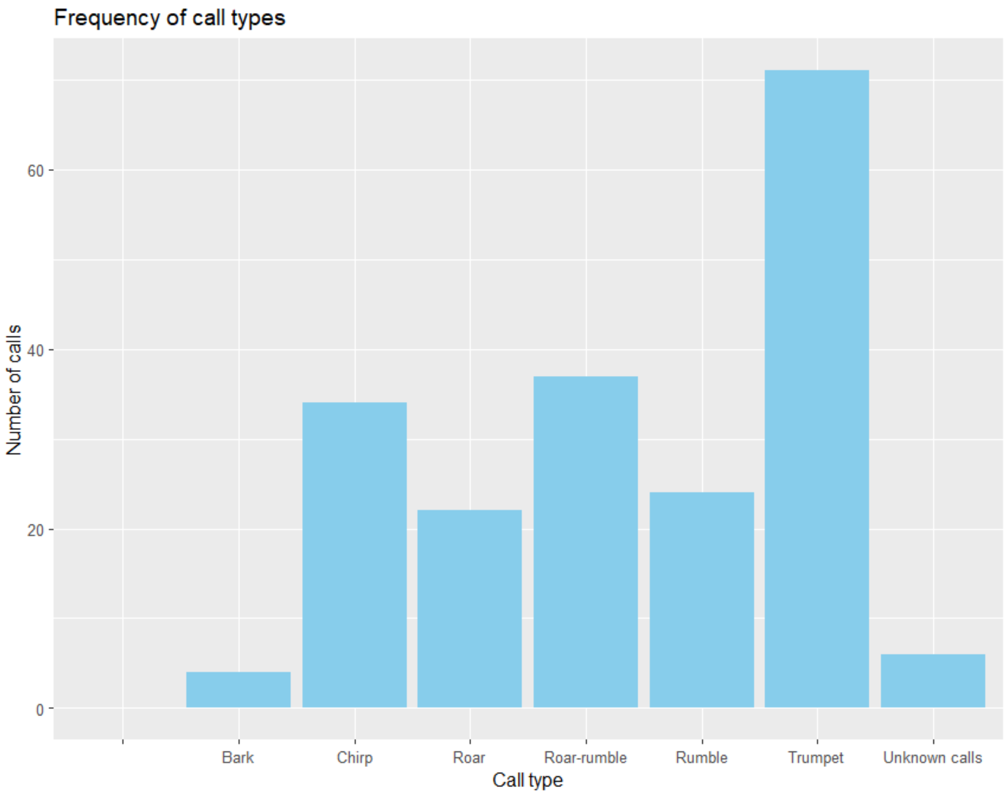


Fig23. The above figure depicts the number of times each call type was recorded.

Result 2: Measurement of physical attributes of the call

On identifying the different call types and the number of times those call types were recorded in out acoustic device, we then measured the temporal parameters for each call call. We estimated the average of these values for each call type.

1. Central Frequency: The central frequency refers to the midpoint or the point in the frequency band at which the frequency is centred.
2. Central time: The central time refers to the timestamp at which the frequency of the spectrum is centred.
3. Peak frequency: Peak frequency indicates the frequency with highest amplitude or intensity in the spectrum. It signifies the dominant frequency component as it highlights the frequency where the spectrum exhibits maximum energy. It is the same as maximum frequency.
4. Maximum time: Maximum time refers to the time at which the frequency at which the highest intesity within the selected range of spectrum.
5. Delta frequency: Delta frequency is a cumulative measure of the frequency across the selected range.
6. Delta time: Delta time is the time for which the cumulative frequency of the selection is calculated. It is also representative of the duration of the call

Sr no	Call type		Number of calls recorded	Number of calls analysed	Central Frequency (Mean)	Delta time (Mean)	Peak Frequency (Mean)	Max Frequency (Mean)	Center time (Mean)	Delta frequency (Mean)	Max time (Mean)
1	Trumpet		71	48	764.45±459.98	1.30±1.51	730.56±501.56	730.56±501.56	1531.62±1329.15	1563.47±620.95	1531.60±1329.16
2	Roar		22	5	771.93±343.66	1.28±1.92	737.30±402.45	737.30±402.45	1503.75±1055.84	1557.82±657.55	1503.73±1055.90
3	Chirp		34	18	1103.19±491.37	0.58±0.63	1094.63±544.70	1094.63±544.70	71.74±27.12	1430.63±511.09	71.75±27.10
4	Bark		4	2	554.37±38.22	0.25±0.03	545.58±50.65	545.58±50.65	2892.08±2.31	1593.68±3.45	2892.08±47.8
5	Rumble		24	16	150.45±135.61	3.44±2.17	173.92±178.02	173.92±178.02	1144.20±951.009	398.90±260.51	1143.99±950.79
6	Roar-rumble	Roar			423.47±146.19	1.01±0.36	385.91±151.40	385.91±151.40	84.97±6.96	1288.84±432.44	89.09±53.26
		Rumble	37	20	195.31±117.80	1.62±0.63	168.45±117.56	168.45±117.56	67.05±2.34	255.63±29.85	67.18±2.43

Table5. Measurement of temporal parameters for different call types.

Vocal Activity Pattern of Elephants:

To understand the pattern of vocal activity of the elephants in our study area. We divided the 24 hours in a day into eight intervals of 3 hours each; for each interval, we noted different call types produced and the number of times they were produced. The figure below shows that the vocal activity was the highest during the 15:00-18:00 interval. However, it is essential to note that all the calls recorded during that time interval belong to a single event in a 1-hour file. Therefore, it does not represent elephant activity at the study site. Based on the data acquired from camera trap images and non-intentional acoustic cues in the audio recordings, we observed that the elephant activity at the study site was high at night, from 6:00 pm to 3:00 pm.

The figure below is representative of different call types recorded on acoustic recorders and camera traps. Therefore, the vocalisations produced between 6:00 am and 12:00 pm were from various locations inside the Cauvery Wildlife Sanctuary. These locations have less to no human activity. On the contrary, no vocal activity of elephants was recorded between 6:00 am and 12:00 pm in the area with high human activity.

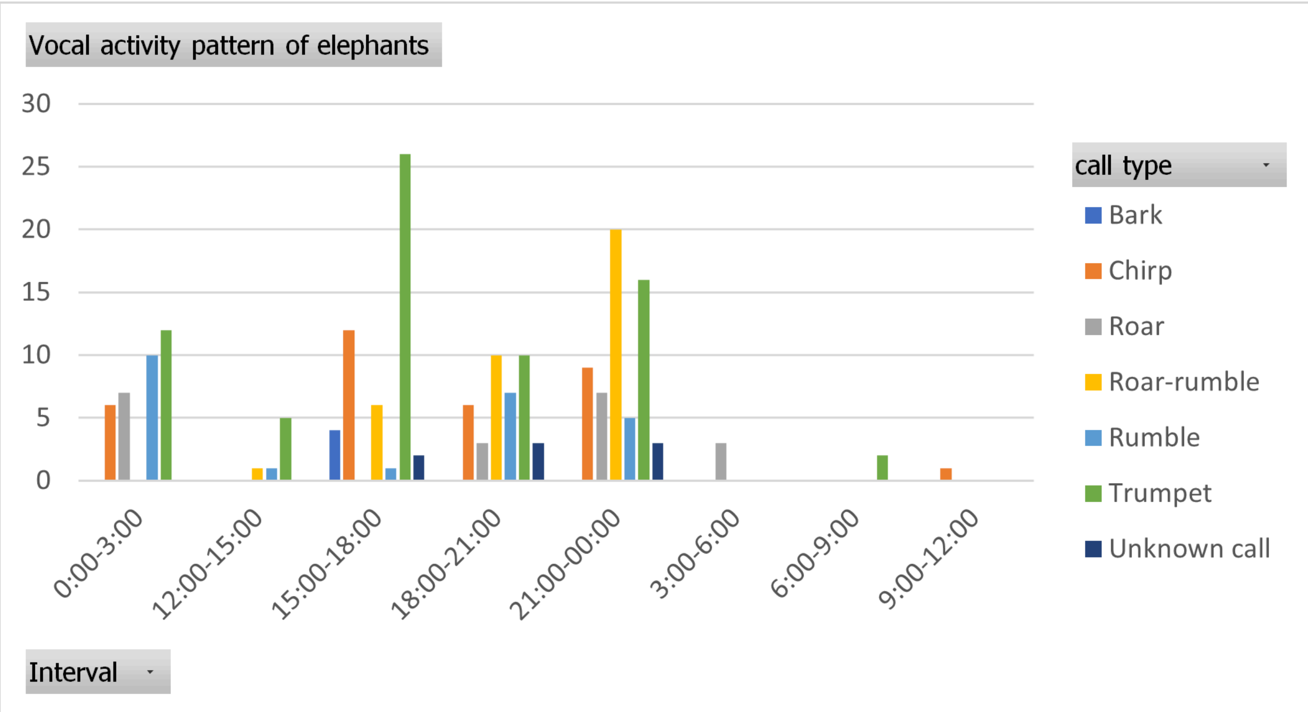


Fig 24. This figure shows the vocal activity pattern of elephants in a day based on the type of calls produced and the number of times each call type was produced.

Chapter 4 Discussion

In this study, we report the effect of the physiological state of musth on the spatial distribution of all the male elephants in our study area and also make a preliminary attempt to understand the pattern of elephant vocalisation in highly human-use areas. We discuss the findings from both studies in two separate sections below:

Section A: Spatial distribution study

The musth periods of the male elephants in our study area show high dependency on the maturity of an individual (Table 4). The table shows that older males tend to have extended and continuous musth periods, while younger males have staggered and asynchronous musth periods.

This observation has also been reported in studies on both Asian(Sukumar,2003; Jainudeen et al.,1972; Srinivasiah et al.,2019) and African elephants(Poole,1987), where males below the age class of 20-25 years do not express periodic and long musth periods. Moreover, upon attaining social maturity, musth develops a cyclic pattern(Lincoln & Ratnasooriya,1996). However, it is essential to note that unlike Rutting in ungulates (McCullough et al.,1981), must is indeed aperiodic and occurs sporadically in male elephants during certain times of the year, in response to specific environmental cues(Poole & Granli,2011). Therefore, Table 4 only indicates the pattern in which musth occurs in different individuals and does not represent a particular season or cycle of musth in those individuals! However, musth is known to have a set pattern of occurrence among individual male elephants. In other words, each male elephant is known to have a set period of musth occurrence even though, generally, male elephants can come into musth at different times of the year.

Apart from the maturity of an individual, musth also shows a dependency on the individual's body condition. An individual with a good body condition can come into musth more frequently and hence have a higher reproductive success(Chelliah et al.,2013). In our study, however, we observe that the individuals' body condition scores stay constant irrespective of their musth statuses (Fig.14 & Fig.15). This may be because our study area consists of human-dominated landscapes that provide access to the elephants in the crop fields, ensuring high nutritional quality throughout the year. The availability of better quality forage may also explain extended musth periods in bulls in our study area(Srinivasiah et al.,2019).

Once in musth, males spend much of their time searching for estreous females in the vicinity. However, due to the staggered nature of the reproductive cycle in females(Sukumar,2003), the number of females in oestrous at any given time is limited. Musth bulls may often occur closer to the herds(Keerthipriya et al.,2019); however, due to the limited access to mates, multiple bulls in musth may occur closer to the same herd. Therefore, we may expect the distances between these bulls to be shorter. In our study, we thus observe that irrespective of the maturity status of an individual, the inter-bull distances when the bulls were in musth were much shorter than when they were not in musth.

Although not significant in our results, we notice that younger individuals(SM) tend to avoid older individuals(SSM) in musth(Fig.17-right). This may be because the the younger males avoid confrontation with an older male due to the risk of competition and agonistic interactions(Sukumar,2003). Moreover, older males in musth have not only periodic, consistent and longer musth cycles compared to the younger bulls but also an alteration in the chemical composition of the musth when an individual progresses towards the SSM age class from the SM age class. Musth secretion in younger males contains esters and alcohols that emit a sweet-smelling odour to avoid confrontation by an older bull(Santiapillai et al.,2011). On the other hand, the musth secretion in older bulls is relatively unpleasant as it is composed of chemicals like frontalins and nonanones, which discourages younger bulls from advancing towards older bulls in musth (Santiapillai et al.,2011).

At a population level, we have seen that biological and sociological factors like sex, maturity, physiological state, and grouping patterns influence behavioural decisions in elephants. However, studies have shown that at an individual level, individual idiosyncrasies play a crucial role in defining an elephant's behaviour that may not resemble the trends observed at the population level(Srinivasaiah et al.,2012). These idiosyncratic behaviours help the individual males to adapt to the competitive pressures of mating and resource utilisation in the wild. Therefore, each individual can use a different mating strategy based on his own social needs. The same can be seen in our results when we individually compared the difference in the distance between elephants depending on the musth status of one individual

Section B: Analysis of Vocal data:

In this study, we classified the vocalisations of Asian elephants into five mutually exclusive categories and one combination call based on their structural features: Trumpets, Roars, Chirps, Rumbles, Barks and Roar-Rumbles.

Amongst all the call types, Chirps had the highest values for the peak, delta and central frequency parameter measurements. Moreover, spectral structures make them easily distinguishable from other call types. Chirps occur in bouts of multiple units, each 2-3 seconds long. Following chirps, trumpets, and roars were the next high-frequency calls with comparable values for Ccentral, peak and delta fFrequencies. However, the two can be distinguished based on their spectral features. Unlike roars, trumpets are harmonic in nature and have a certain temporal structure. On the other hand, roars appear as dark smears, are low in harmonicity, and lack a specific temporal structure.

Conversely, rumbles,, had the lowest values for all the frequency parameters. Rumbles in Asian elephants exhibit various acoustic features and are the only call type with an infrasonic frequency component. Due to infrasonic components, studies on Asian (de Silva et al., 2010) and African (Poole,2011) elephants show that rumbles facilitate group movement coordination and cohesion within the herd. However, we could not report any infrasonic rumbles in this study as our selected location had high human activity. Since certain anthropogenic sounds, like vehicle noise, are also known to have infrasonic components, it was challenging to report infrasonic sounds from the elephants at this location.

Moreover, out of all the calls recorded at our study site, rumbles were the most prolonged, with the highest recorded duration of 8 seconds. The values for the physical and spectral attributes of the calls recorded at our study site coincide with previous studies on the vocal repertoire of Asian elephants in Sri Lanka (de Silva, 2010) and Mudummalai Tiger Reserve in Southern India (Nair et al.,2009). Of the 198 calls recorded, 68 were trumpets, followed by 25 roar-rumbles and 20 chirps. Considering the previous studies on these call types, we observe that trumpets, roar-rumbles and chirps are often produced in the context of aggression, arousal, annoyance and in response to threat (de Silva,2010; Poole,2011). Therefore, the higher occurrence of these call types may be explained by the location at which calls were recorded. The high vocal activity observed for the time interval 15:00-18:00 was from one file (Fig.32), which could be due to high human activity and human noises (directed towards the elephant) on that particular day, not necessarily reflecting the true nature of the vocal activity of elephants in the study area.

CONCLUSION

Musth is asynchronous and can occur anytime throughout the year, unlike other seasonally breeding animals that display rut or rut-like behaviour at a specified period. Musth periods in an individual show dependency on age and body condition, resulting in older males having longer and consistent musth periods. Musth's relevance as a reproductive strategy also requires further study to comprehend its adaptive benefit fully.

However, through this study, we were able to establish that musth affects the spatial distribution of male elephants in a landscape. This distribution shows dependency on the maturity status of an individual male. Further, a part of this study provided a preliminary characterisation of Asian elephant vocalisations, where calls were classified into six different call types. From this study, we deduce that elephants produce high-frequency vocalisations like trumpets, roar-rumbles and chirps in areas with high human activity.

The increasing abundance of elephants in a human-dominated area results from anthropogenic factors like deforestation and fragmentation of the forested regions. Understanding the behaviour of elephants in human-dominated landscapes regarding their movement, association, and communication is therefore critical for developing better management measures to reduce human-elephant conflicts.

FUTURE PROSPECTS

The first section of this study was part of a long-term elephant monitoring project that has been carried out since February 2016. In this section the main aim was to carry out a spatial analysis of the effect of musth at the level of a landscape. To establish the same, we selected 47 individual bulls that were recorded to be in and out of musth on camera traps. We randomly chose a single instance in which the particular individual was observed in and out of musth to conduct the analysis for this study. However, most of these 47 individuals were recorded in and out of musth at multiple instances. Considering all of these instances, it is crucial to make a more nuanced argument about the effect of musth on the spatial distribution of males. Therefore, one future prospect of this study would be to analyse all the instances in which these individuals were recorded in musth and not in musth.

The second section of this study dealt with understanding the vocalisations produced by elephants in a human-dominated area. Due to certain logistical contraints, we could set -up the recorder only at a single location inside cauvery wildlife sanctuary, limiting our sampling effort. Therefore, another future prospect for this study would be to sample from more locations with high and low human activity.

Appendix

Appendix A:
<u>Boxplots of distances calculated in musth and not in musth at individual level for all SM individuals</u>

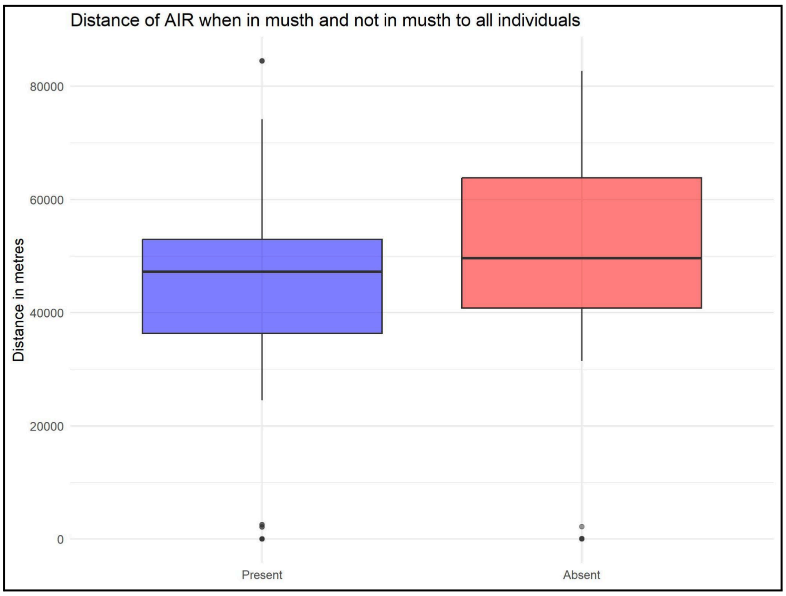


Fig25. The above figure shows the distance of AIR in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)< Distance(Musth Absent). P= 0.003

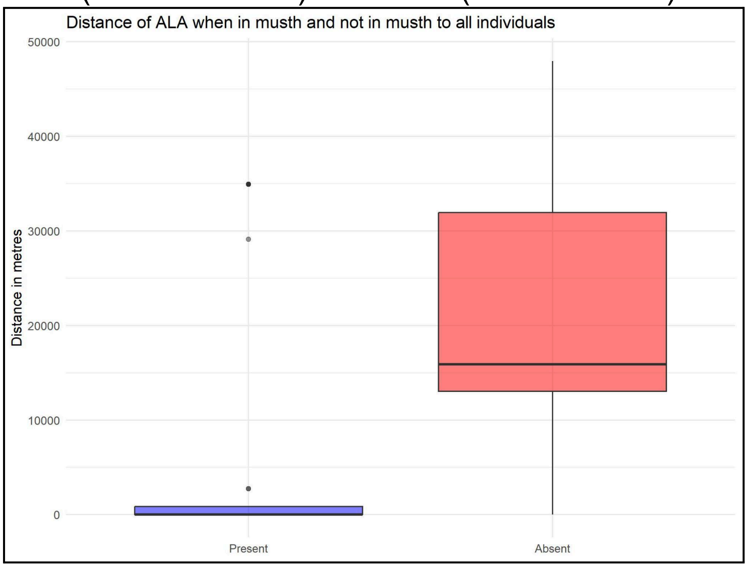


Fig26. The above figure shows the distance of ALA in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)< Distance(Musth Absent). P<0.001

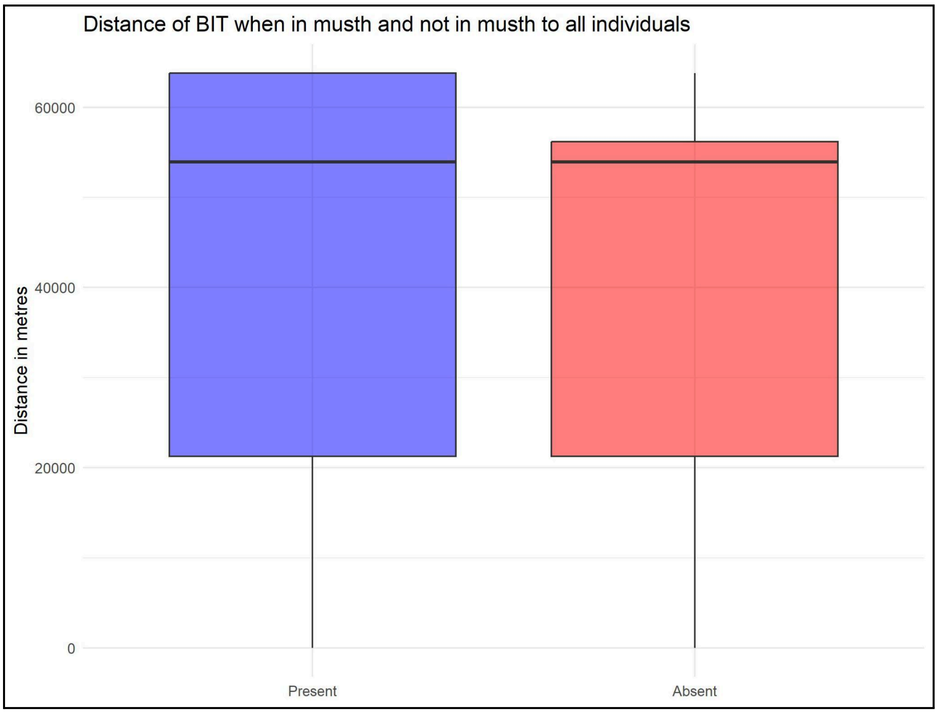


Fig27. The above figure shows the distance of BIT in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)=Distance(Musth Absent). P=1

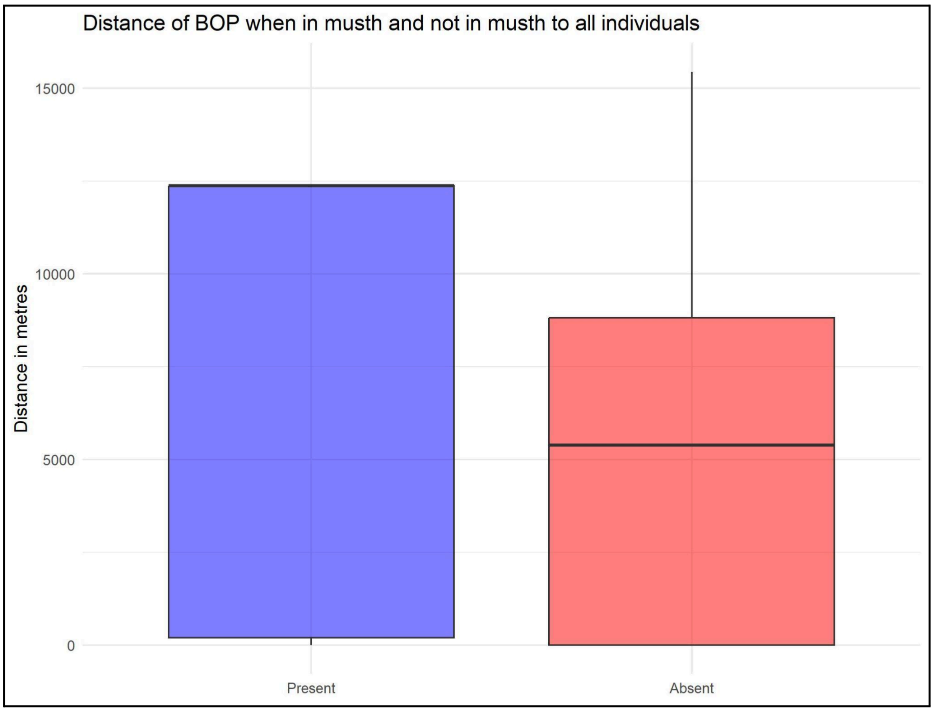


Fig28. The above figure shows the distance of BOP in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P=0.095

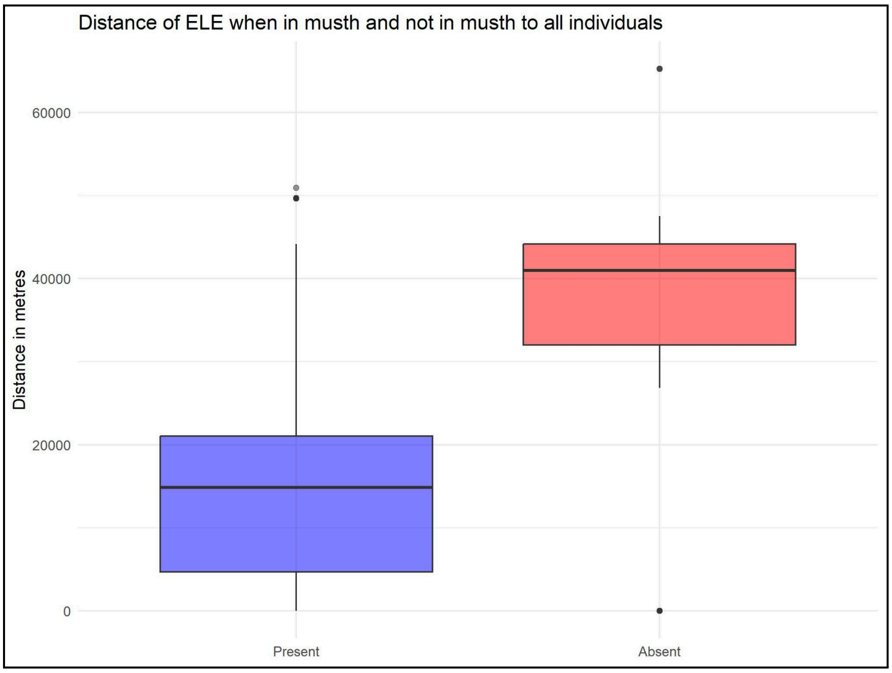


Fig29. The above figure shows the distance of ELE in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)< Distance(Musth Absent). P<0.001

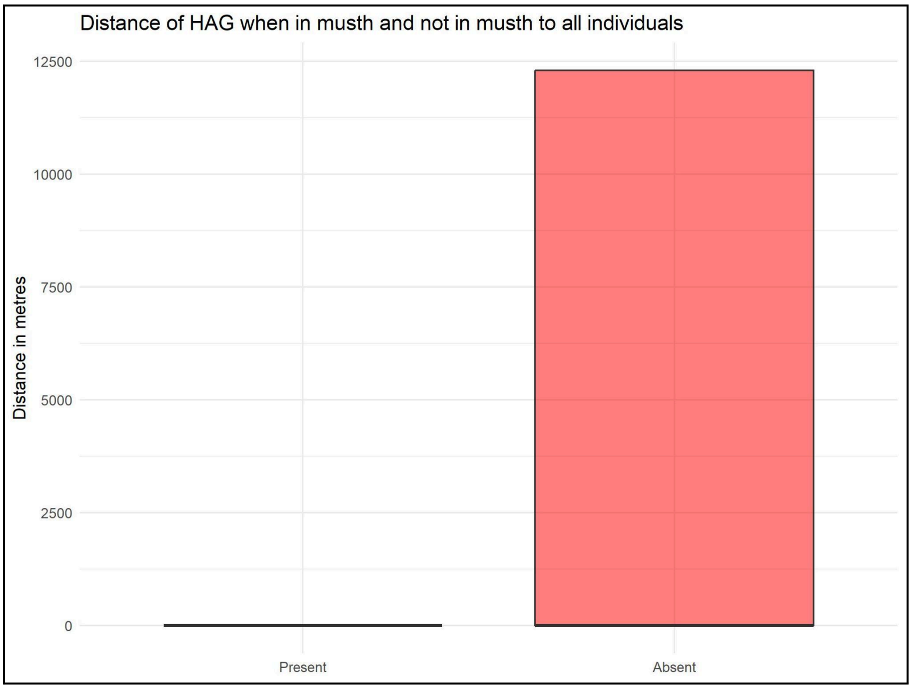


Fig30. The above figure shows the distance of HAG in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)=Distance(Musth Absent). P=1

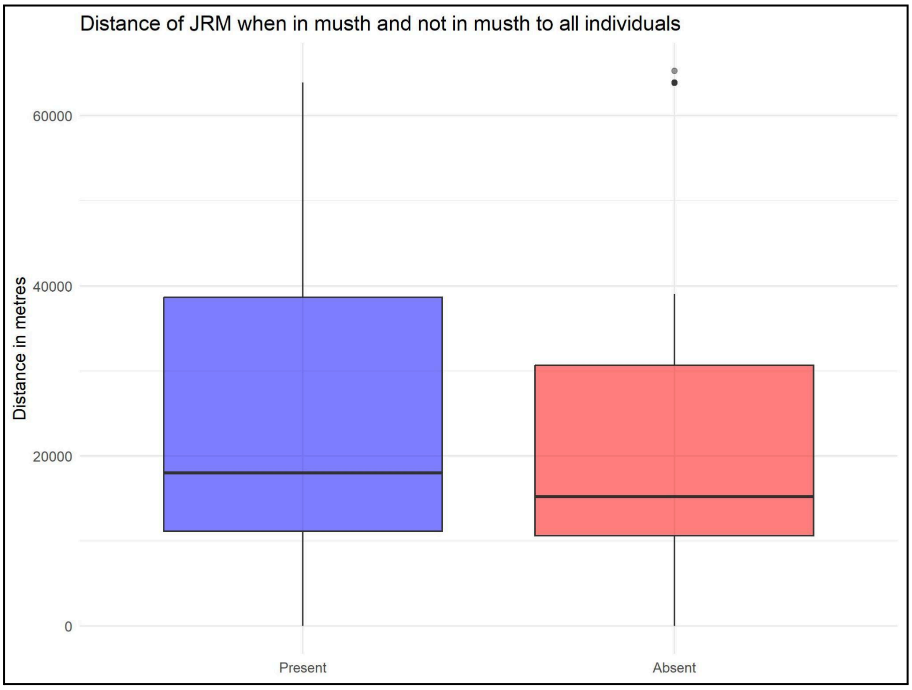


Fig31. The above figure shows the distance of JRM in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)> Distance(Musth Absent). P=0.177

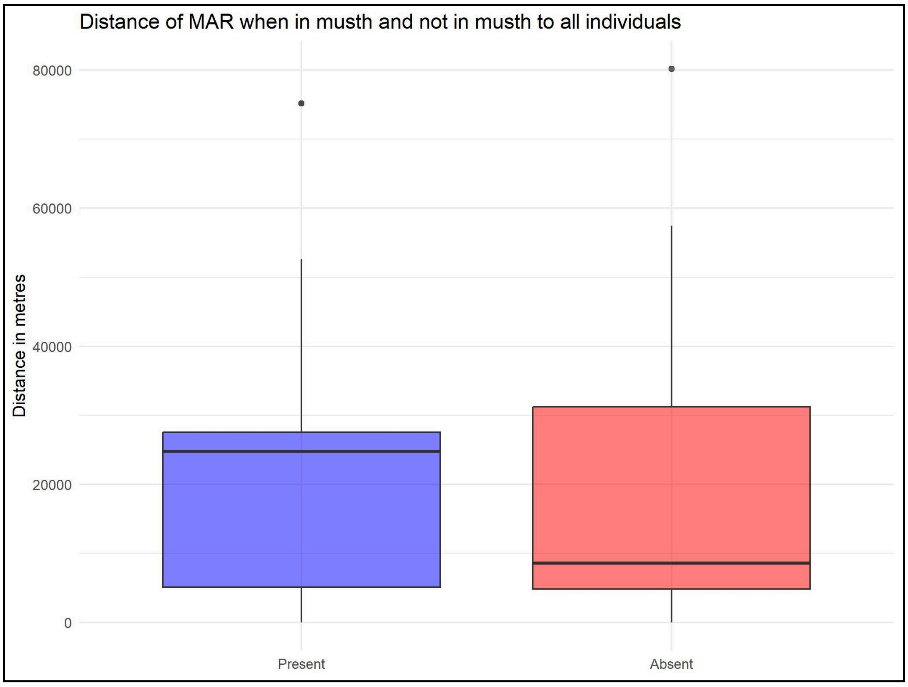


Fig32. The above figure shows the distance of MAR in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P=0.181

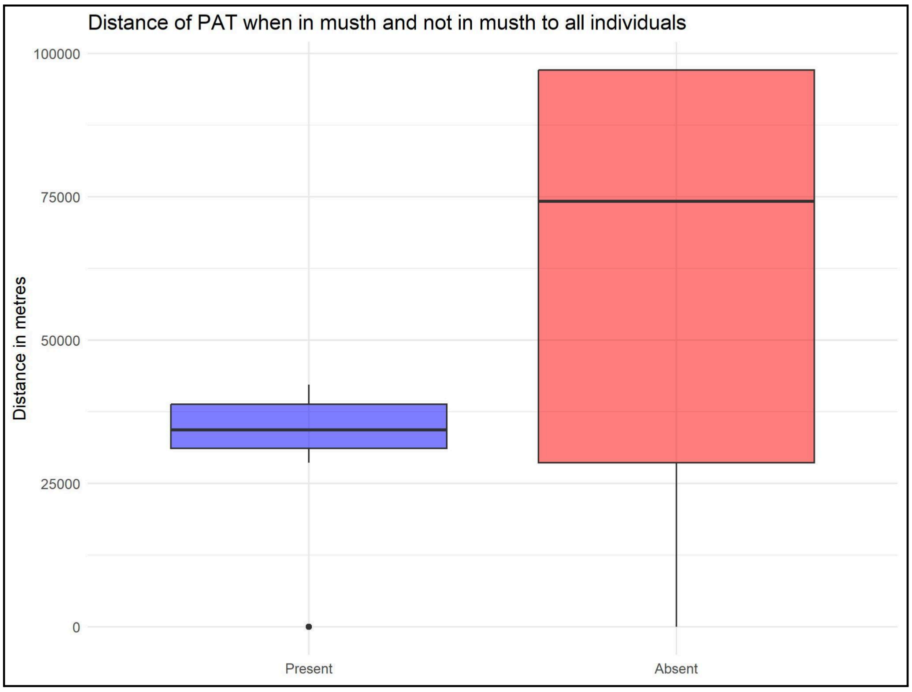


Fig33. The above figure shows the distance of PAT in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)< Distance(Musth Absent). P<0.001

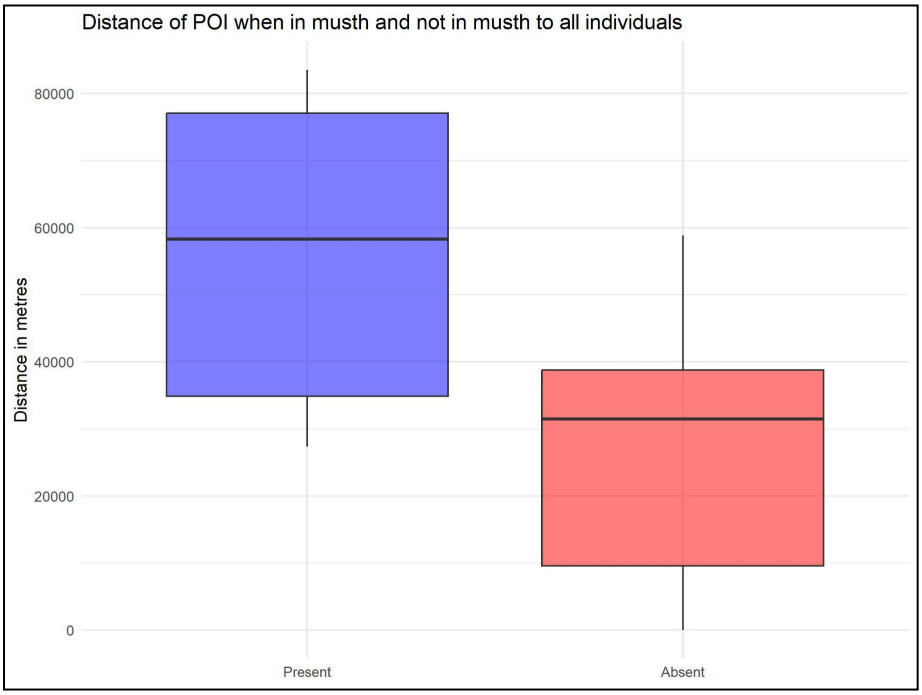


Fig34. The above figure shows the distance of POI in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P<0.009

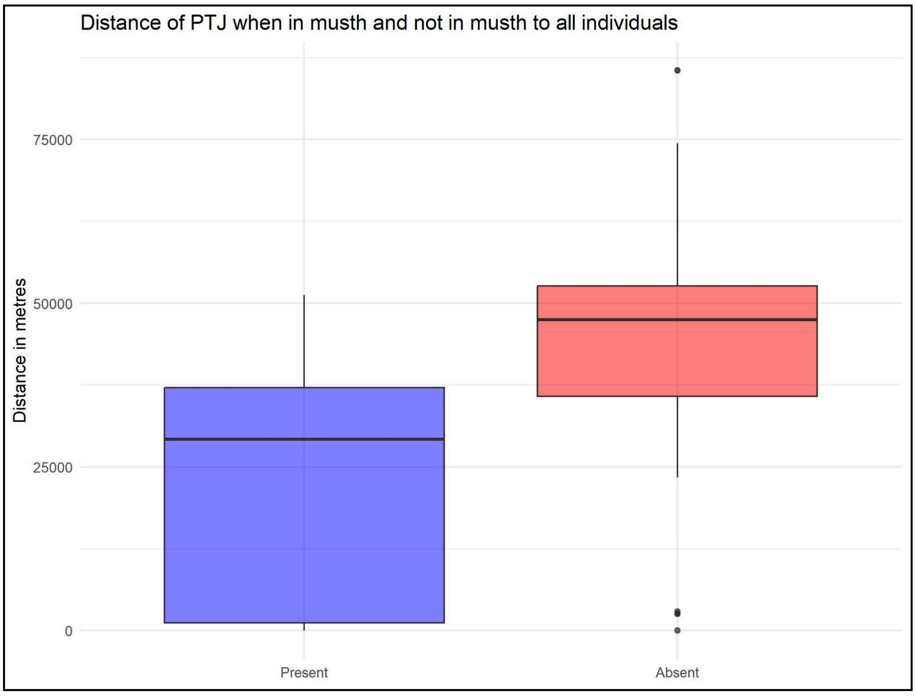


Fig35. The above figure shows the distance of PTJ in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)< Distance(Musth Absent). P<0.001

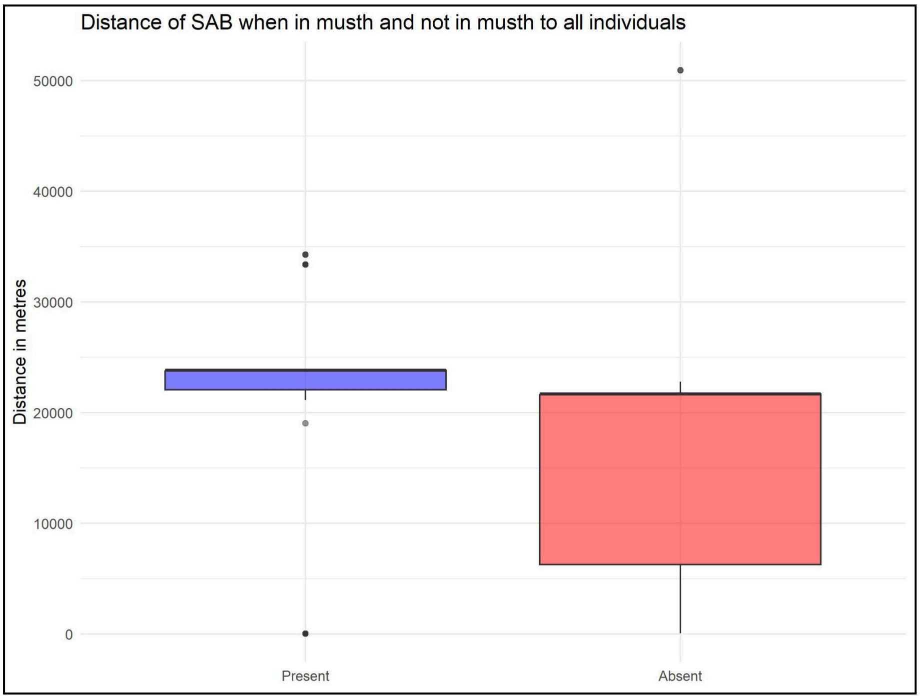


Fig36. The above figure shows the distance of SAB in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)< Distance(Musth Absent). P=0.032

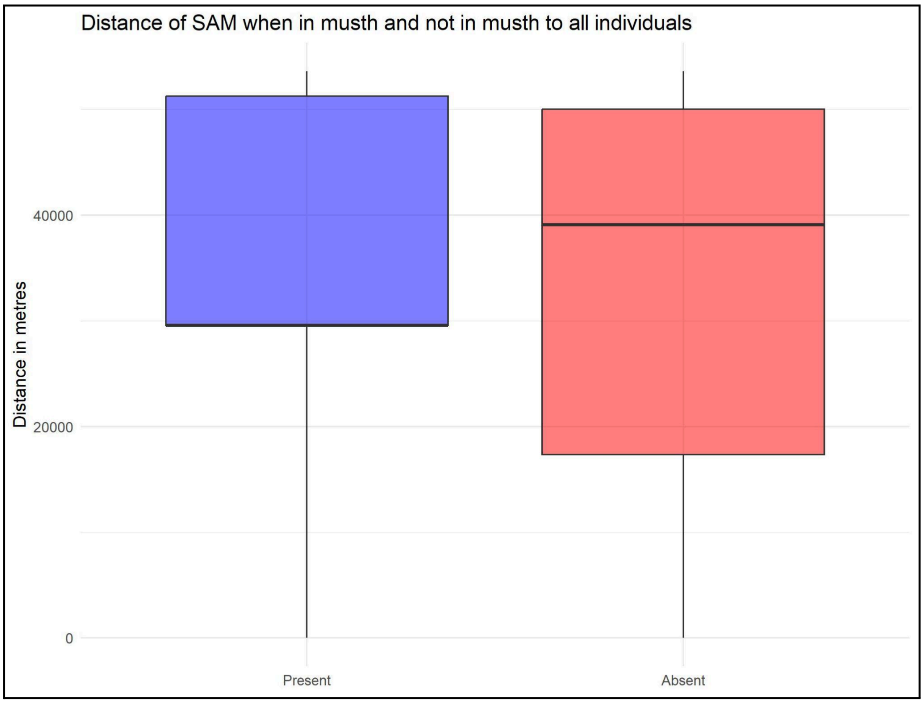


Fig37. The above figure shows the distance of SAM in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P=0.234

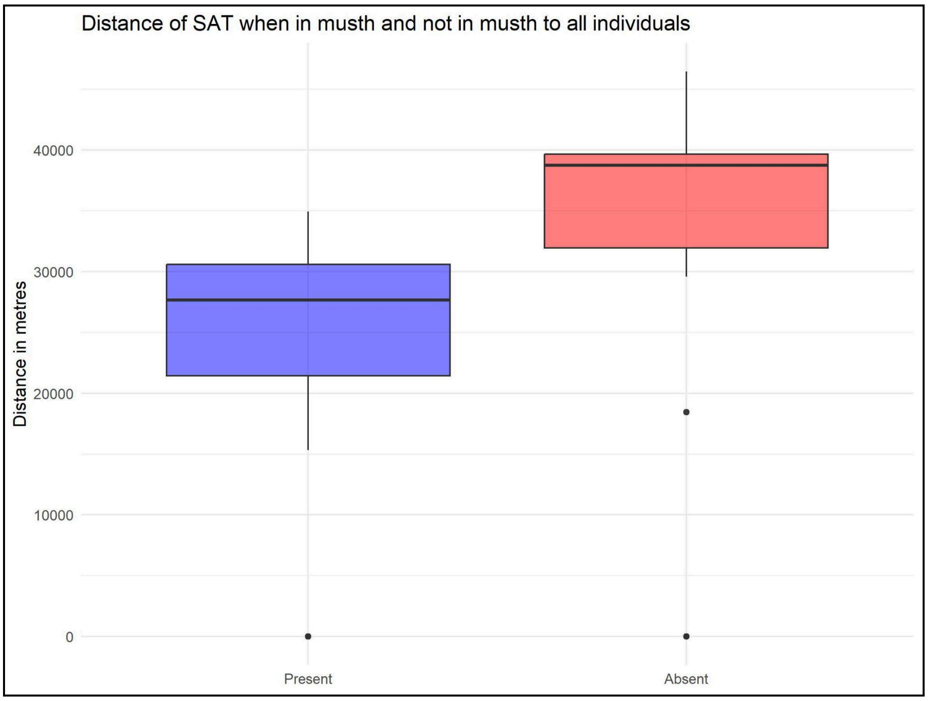


Fig38. The above figure shows the distance of SAT in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P<0.001

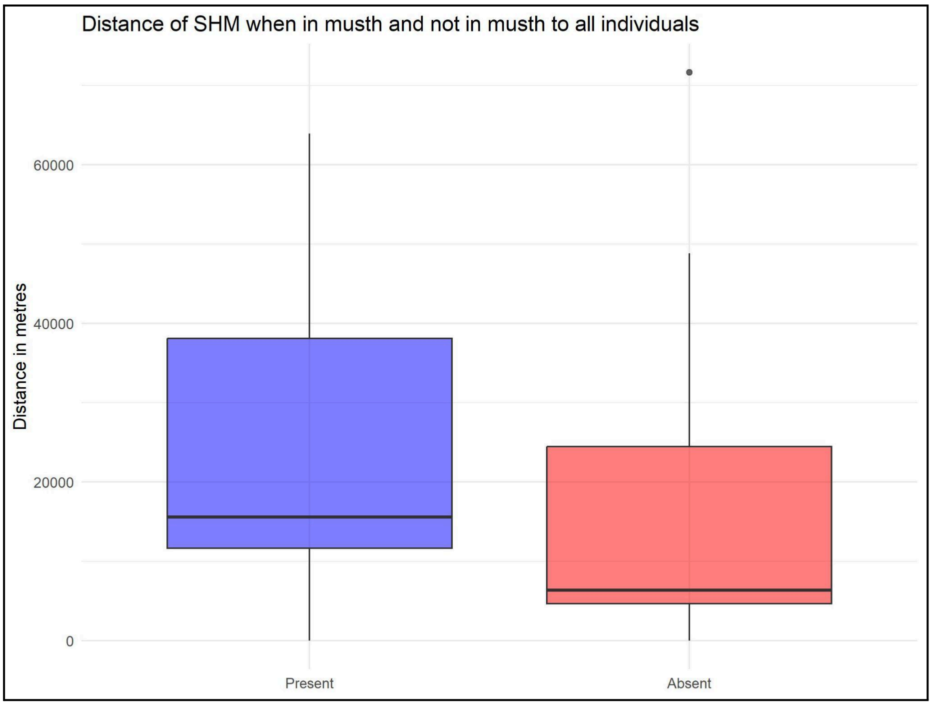


Fig39. The above figure shows the distance of SHM in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P=0.001

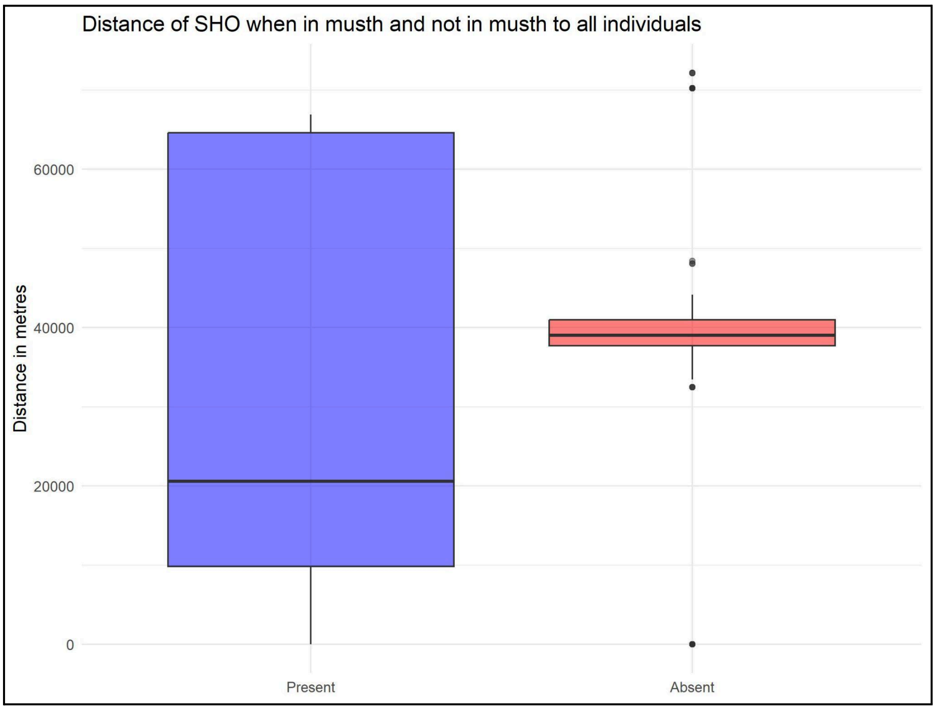


Fig40. The above figure shows the distance of SHO in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P<0.001

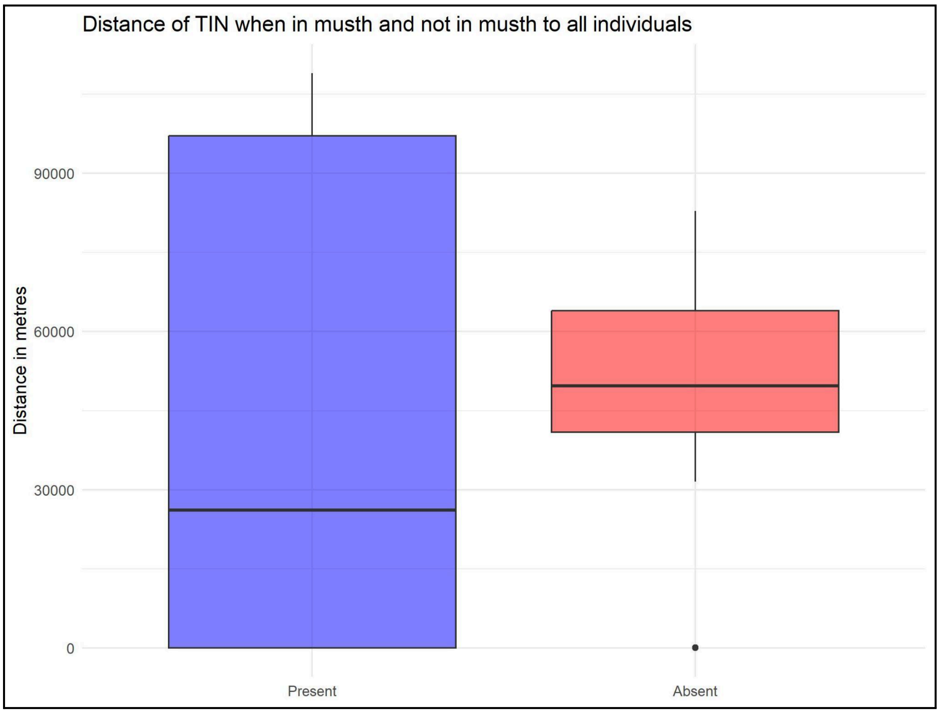


Fig41. The above figure shows the distance of TIN in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P<0.001

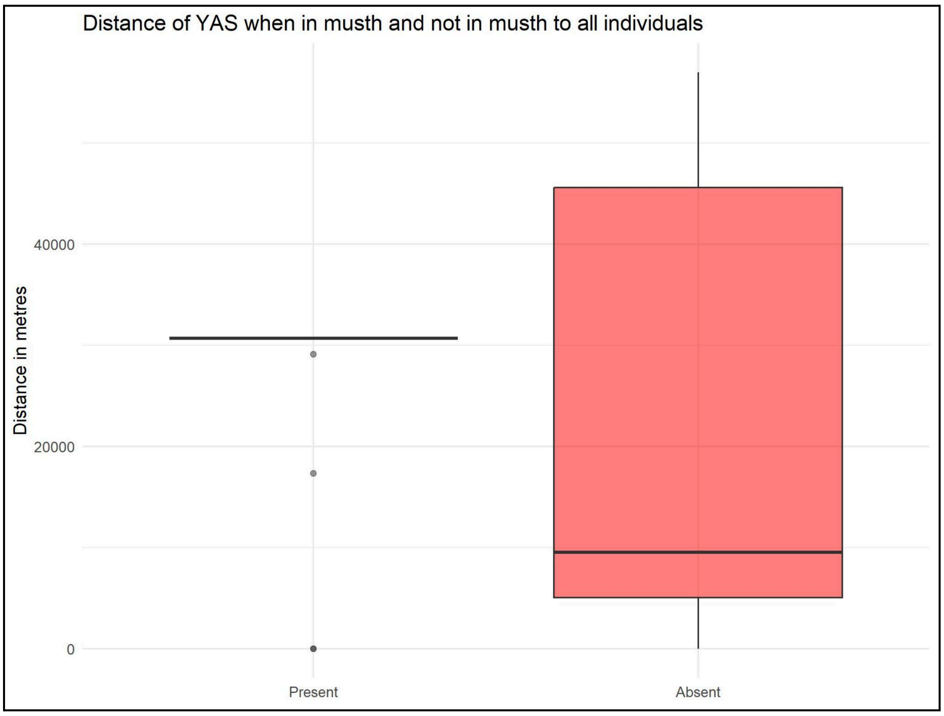


Fig42. The above figure shows the distance of YAS in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P=0.001

Appendix B:

Boxplots of distances calculated in musth and not in musth at individual level for all SSM individuals

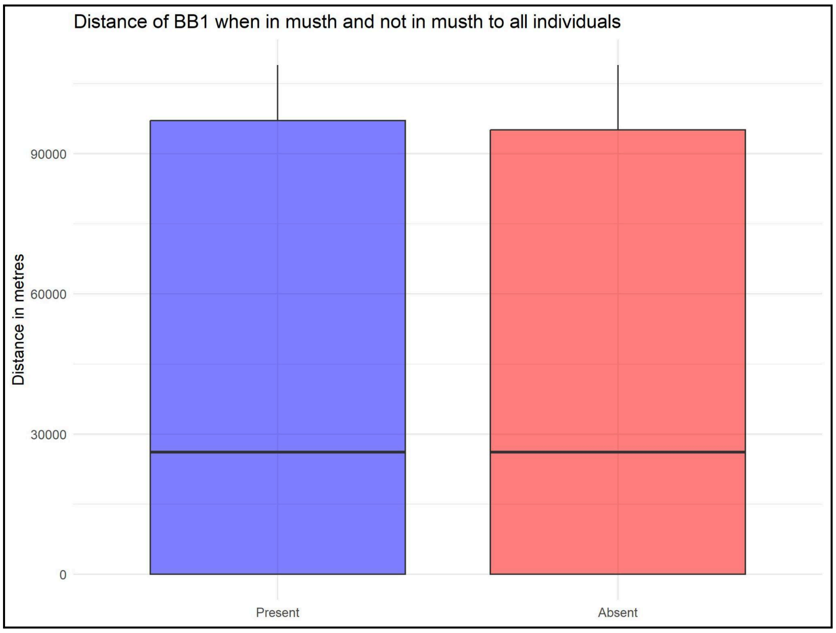


Fig43. The above figure shows the distance of BB1 in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)=Distance(Musth Absent). P=0.993

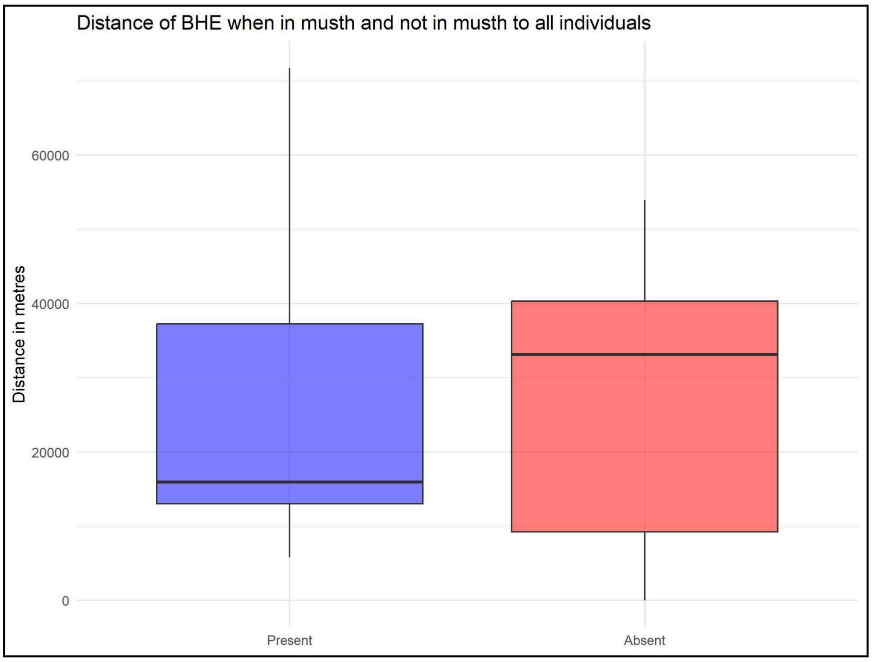


Fig44. The above figure shows the distance of BHE in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P=0.001

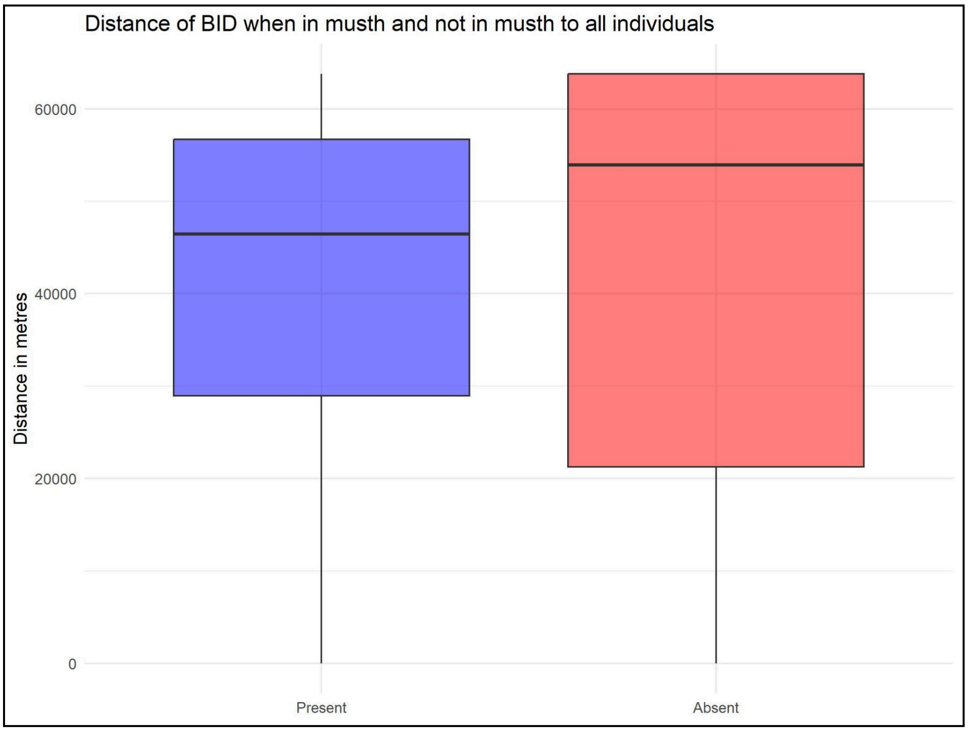


Fig45. The above figure shows the distance of BID in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P=0.073

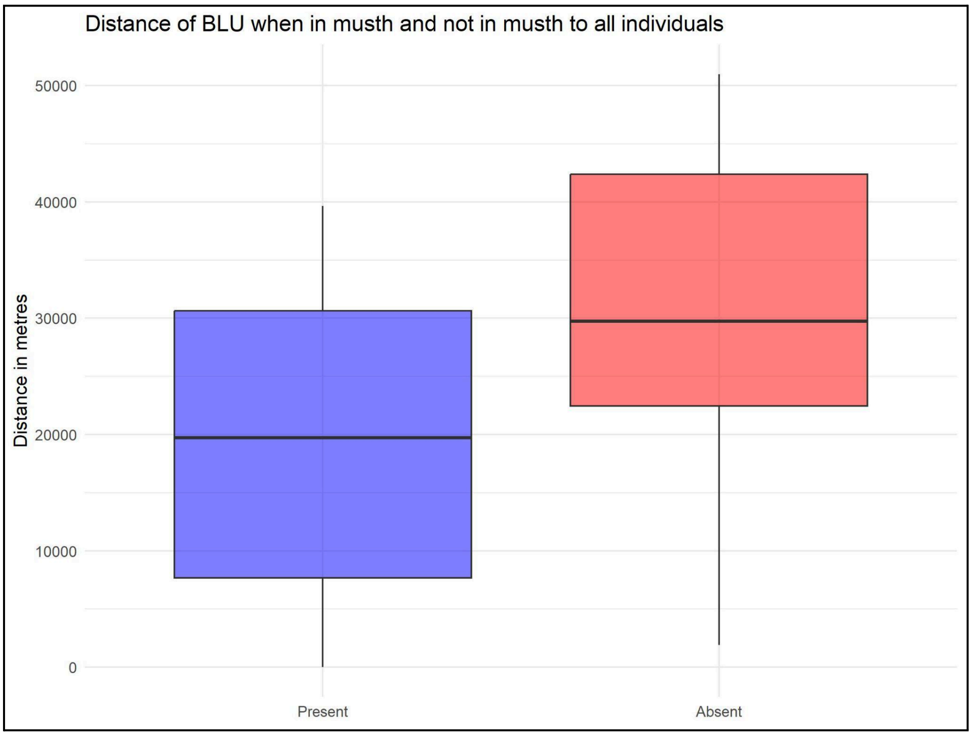


Fig46. The above figure shows the distance of BLU in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P=0.003

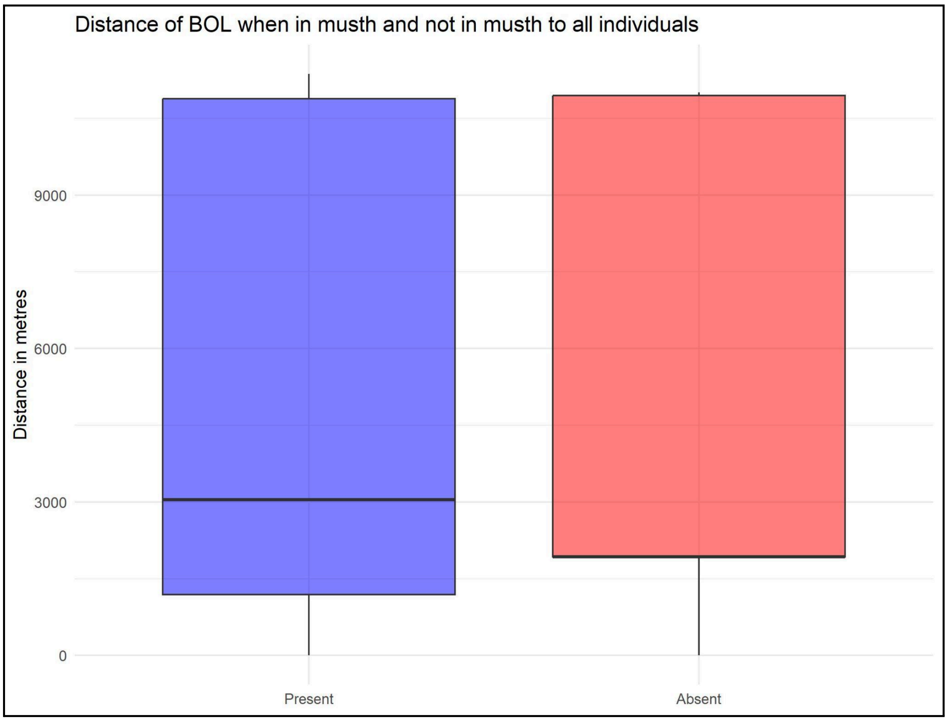


Fig47. The above figure shows the distance of BOL in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P=1

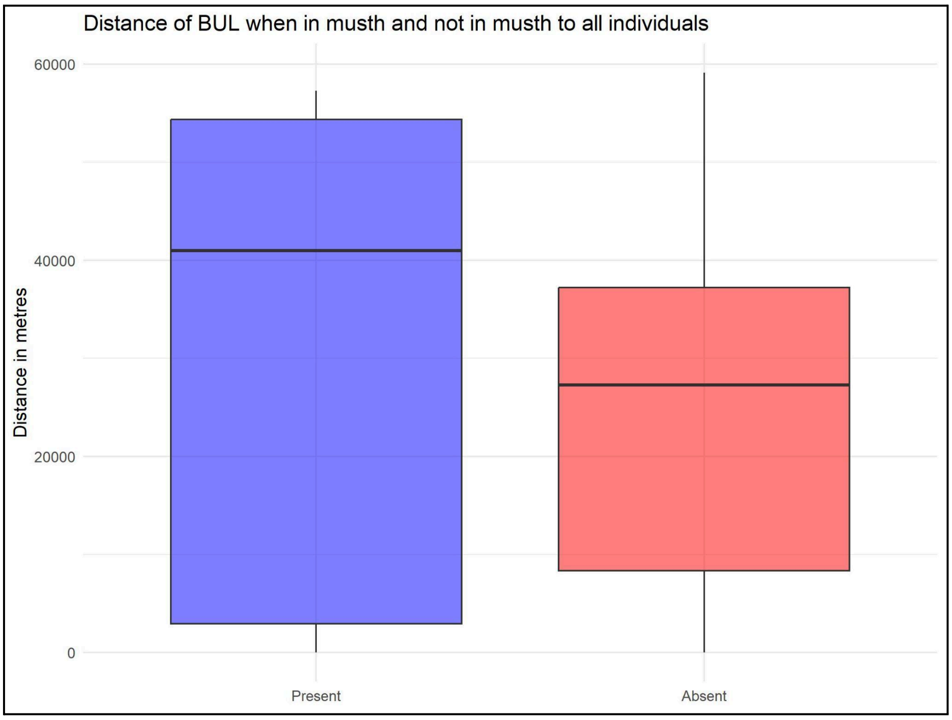


Fig48. The above figure shows the distance of BUL in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P=0.02

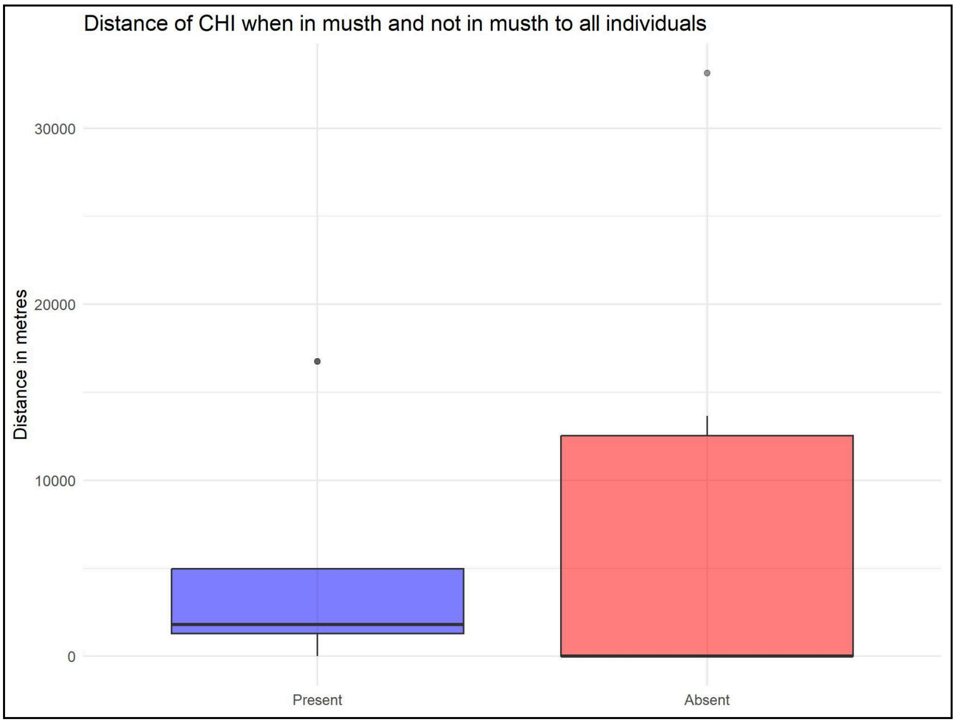


Fig49. The above figure shows the distance of BUL in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P=0.141

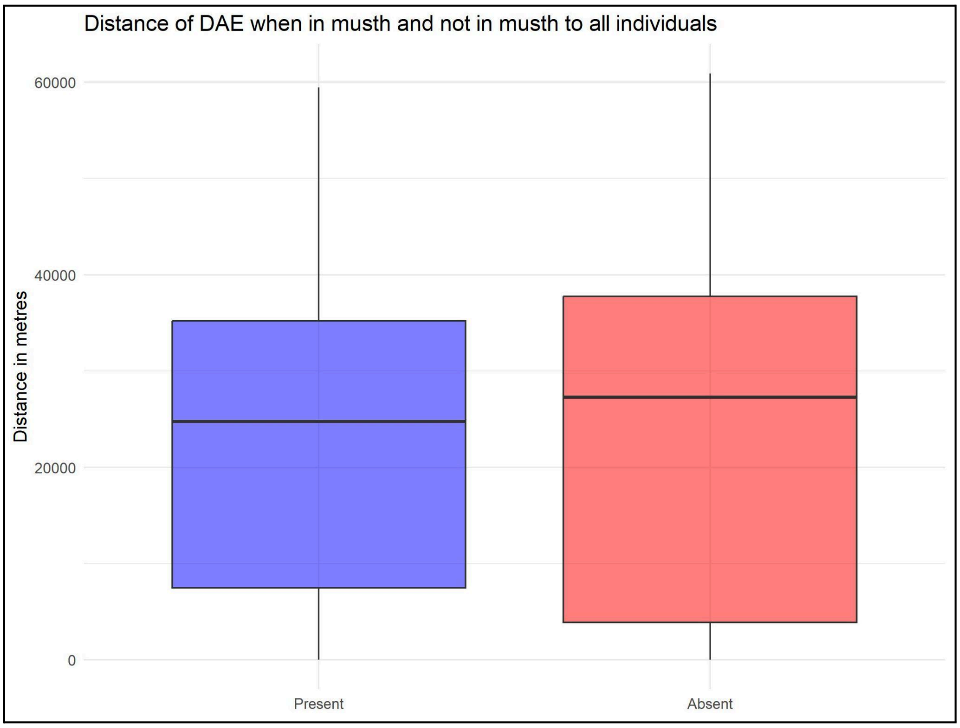


Fig50. The above figure shows the distance of DAE in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P=0.31

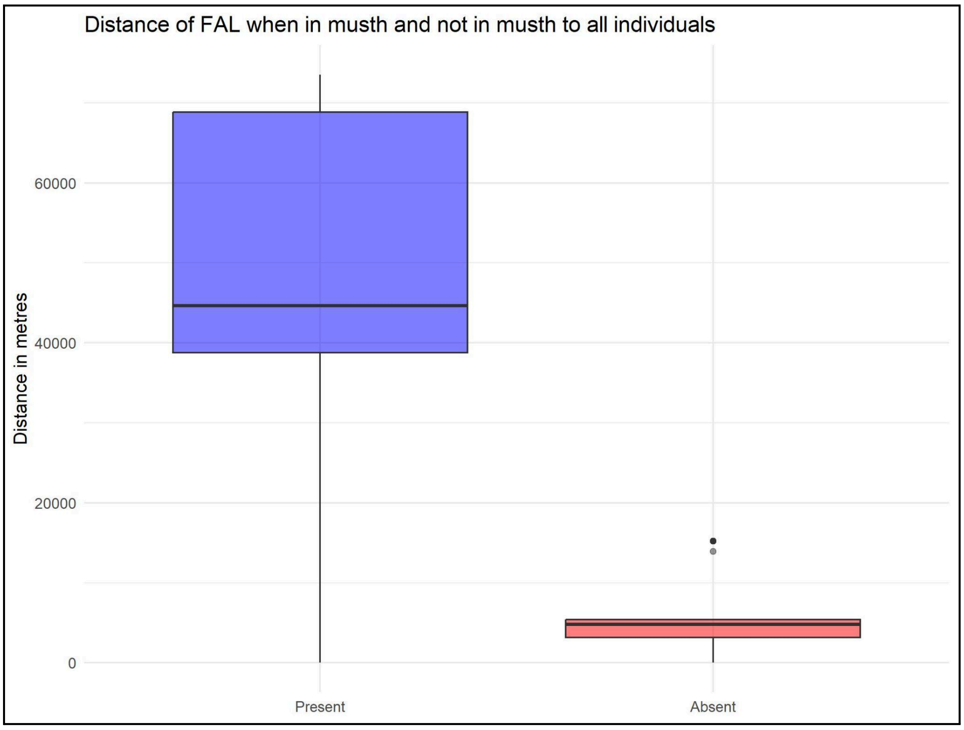


Fig51. The above figure shows the distance of FAL in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P<0.01

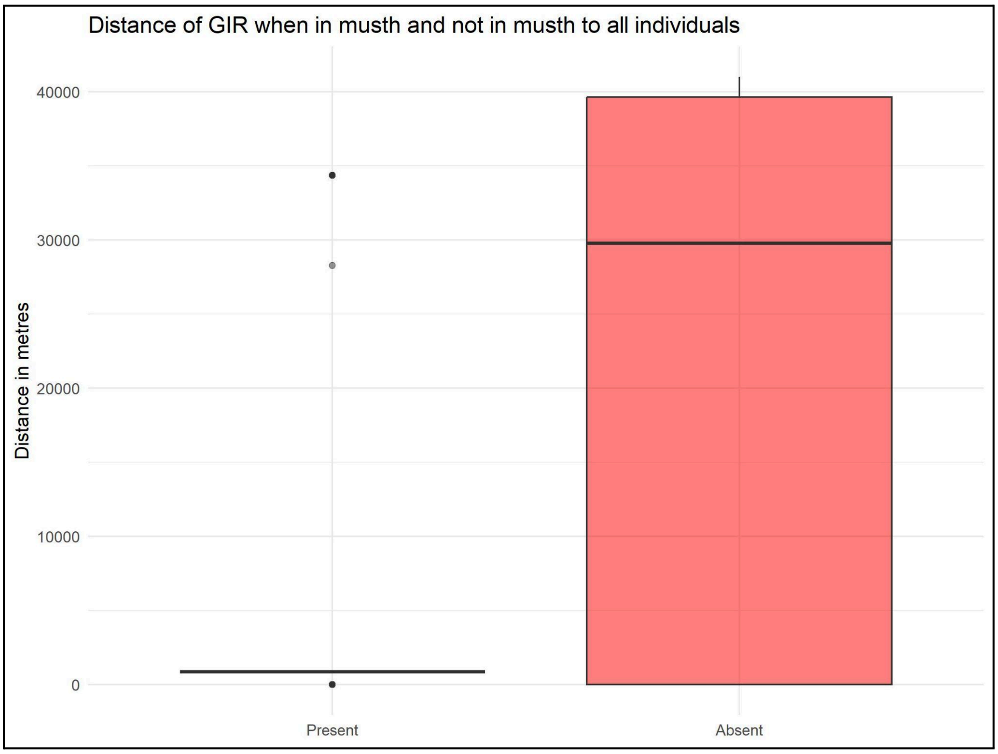


Fig52. The above figure shows the distance of FAL in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P<0.01

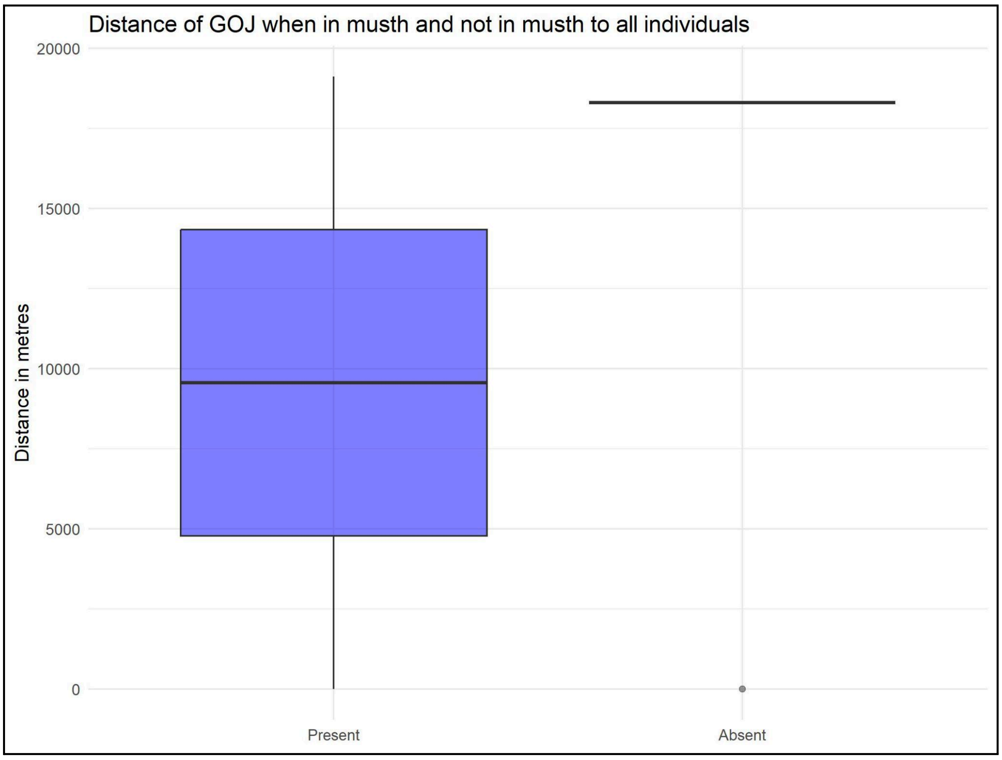


Fig53. The above figure shows the distance of GOJ in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P=0.524

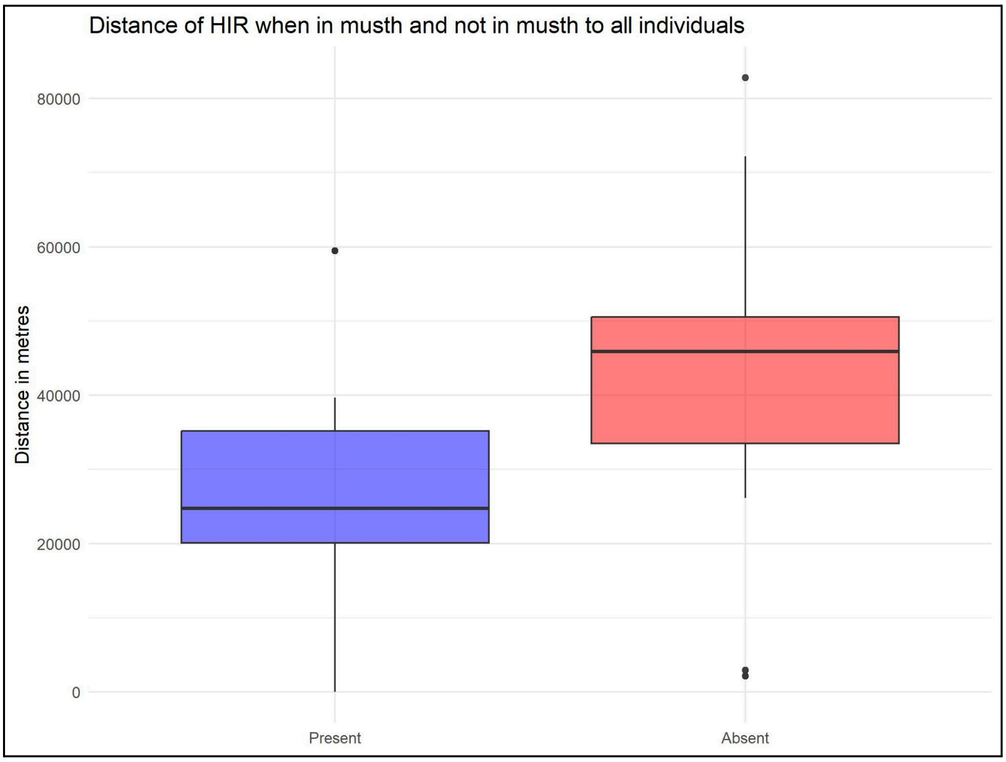


Fig54. The above figure shows the distance of HIR in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P<0.01

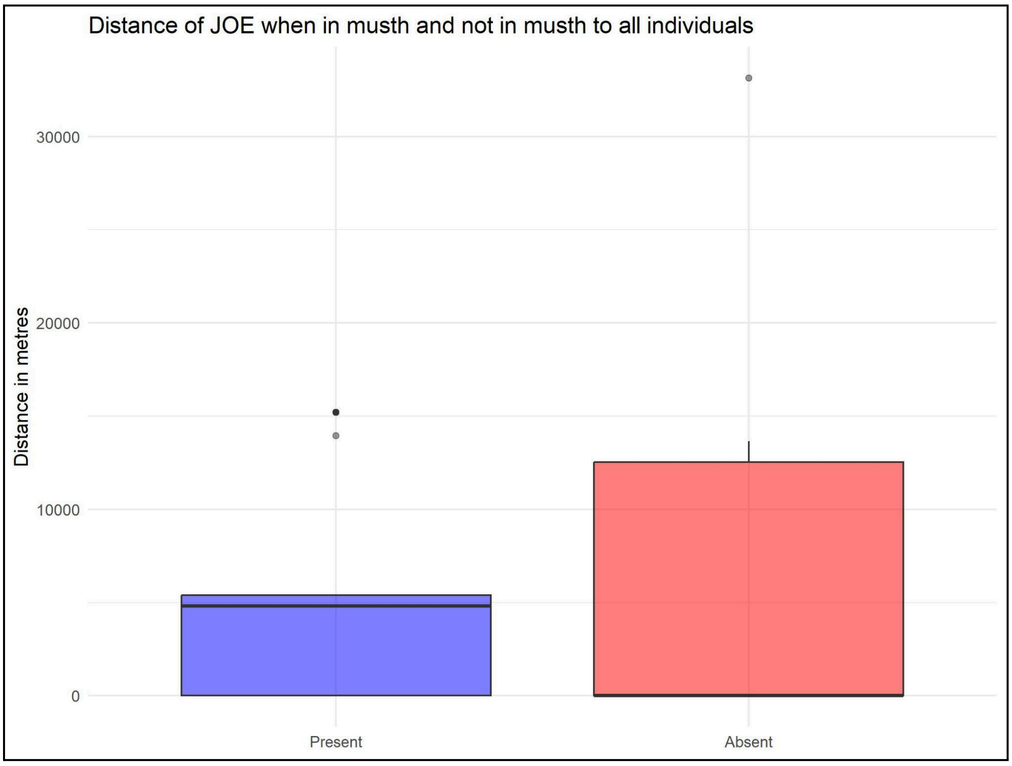


Fig55. The above figure shows the distance of JOE in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P=0.057

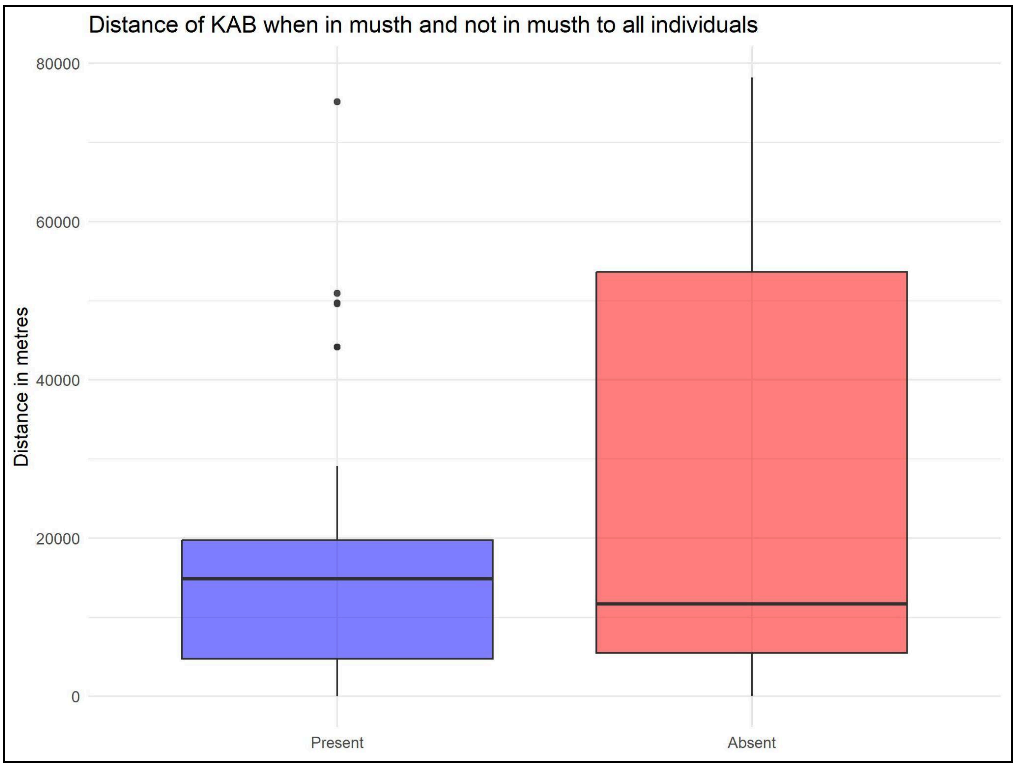


Fig56. The above figure shows the distance of KAB in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P=0.071

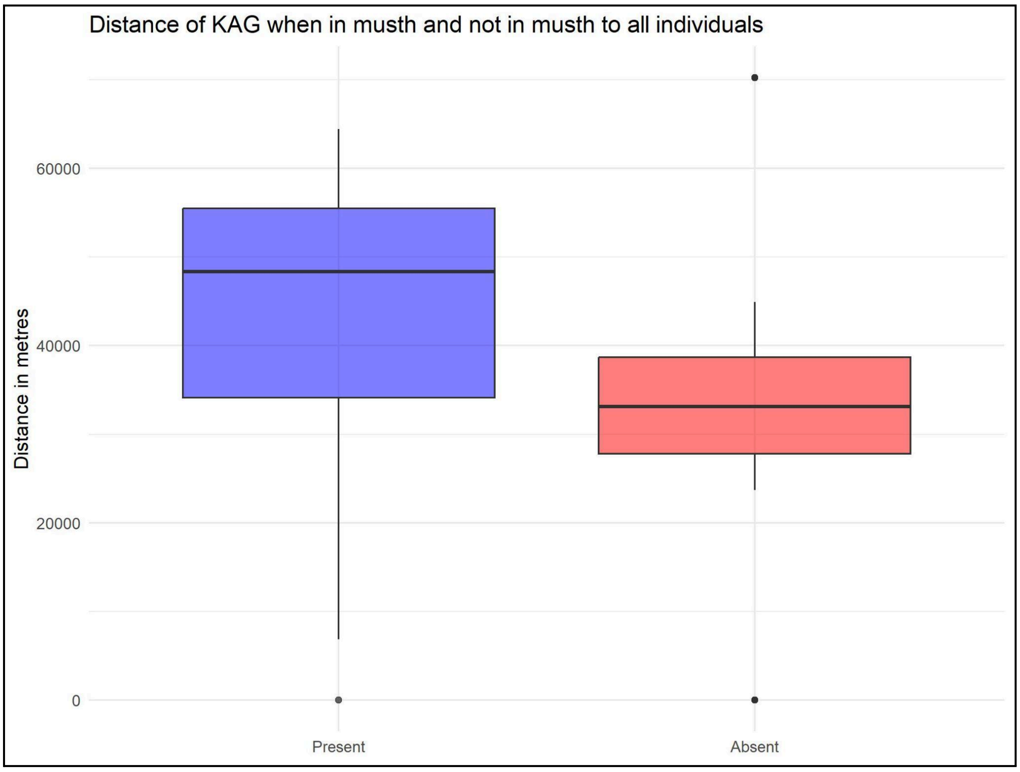


Fig57. The above figure shows the distance of KAG in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P<0.01

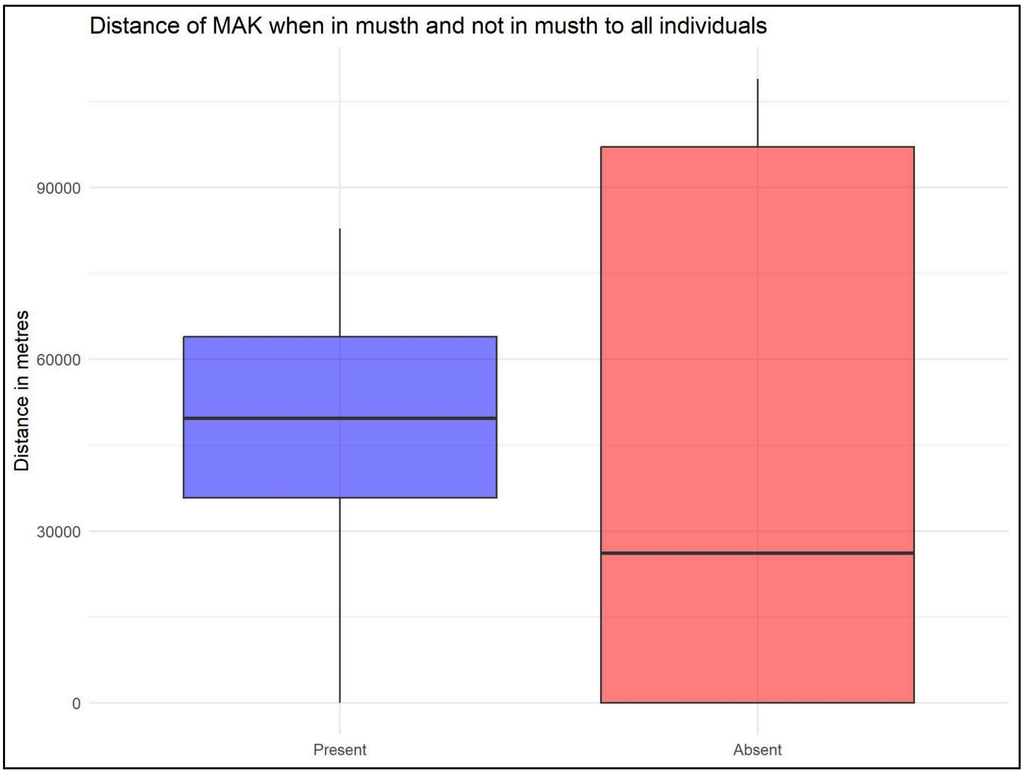


Fig58. The above figure shows the distance of MAK in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P<0.01

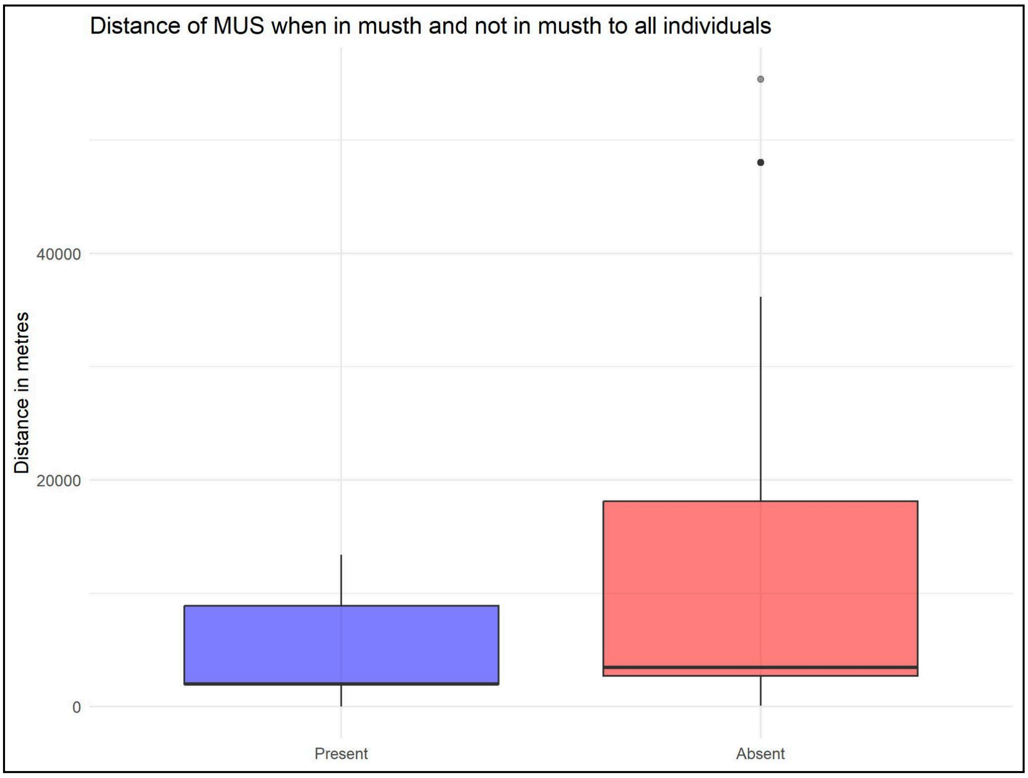


Fig59. The above figure shows the distance of MUS in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). $P<0.01$

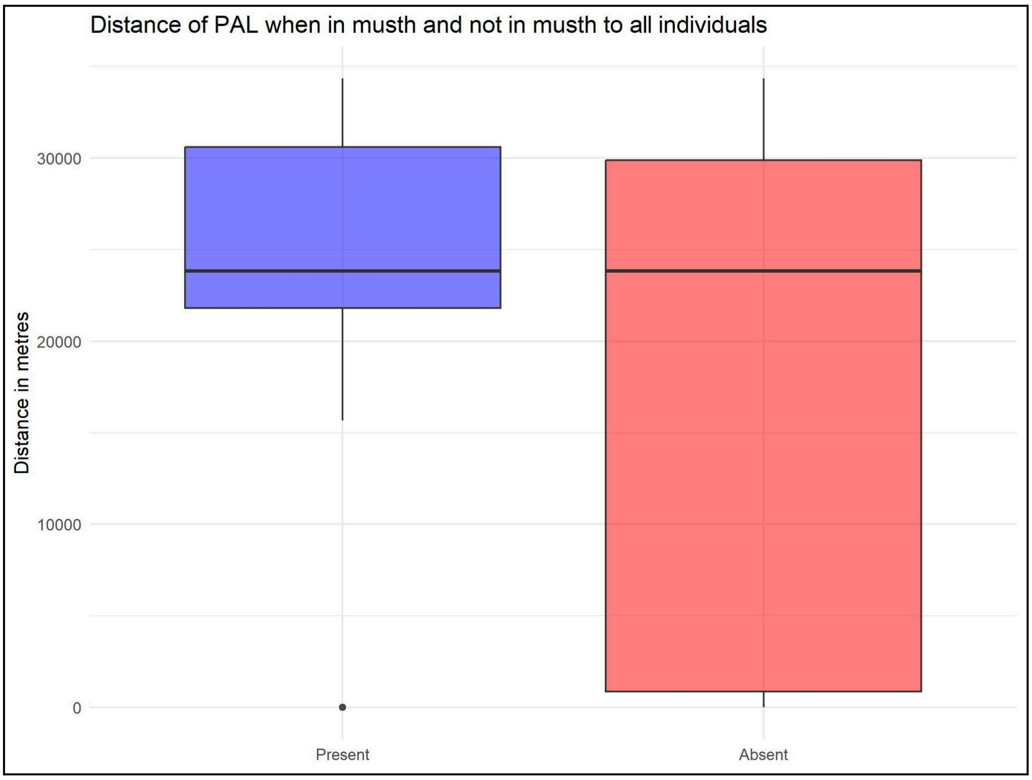


Fig60. The above figure shows the distance of MUS in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that

Distance(Musth Present)=Distance(Musth Absent). $P=1$

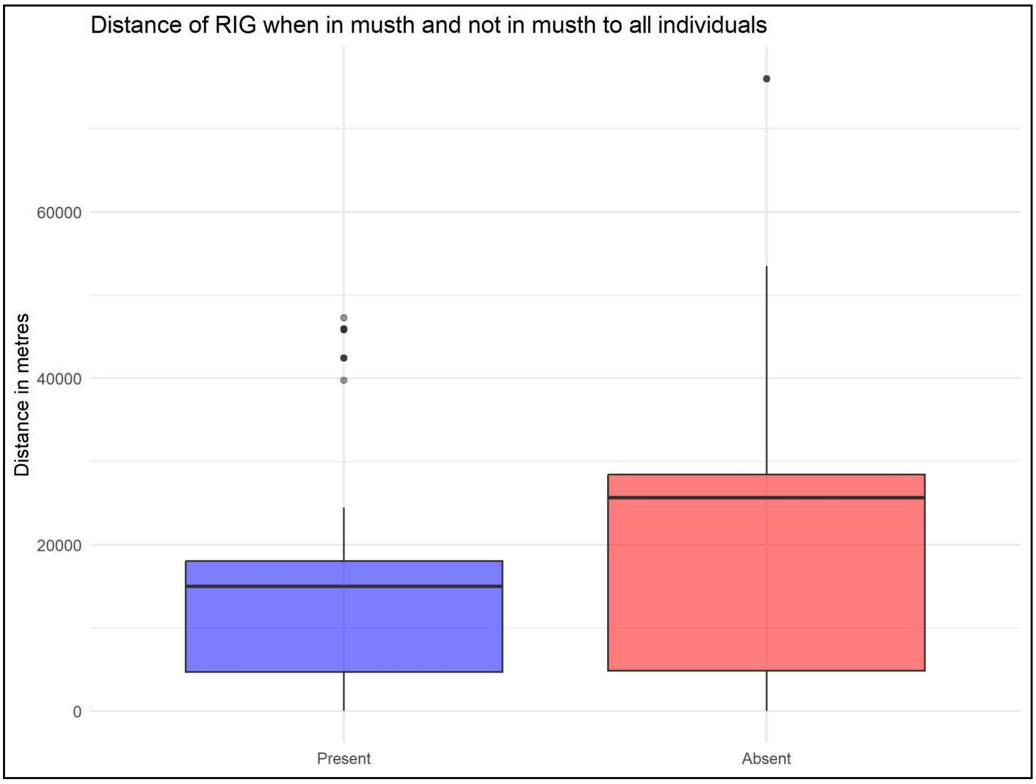


Fig61. The above figure shows the distance of RIG in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P<0.01

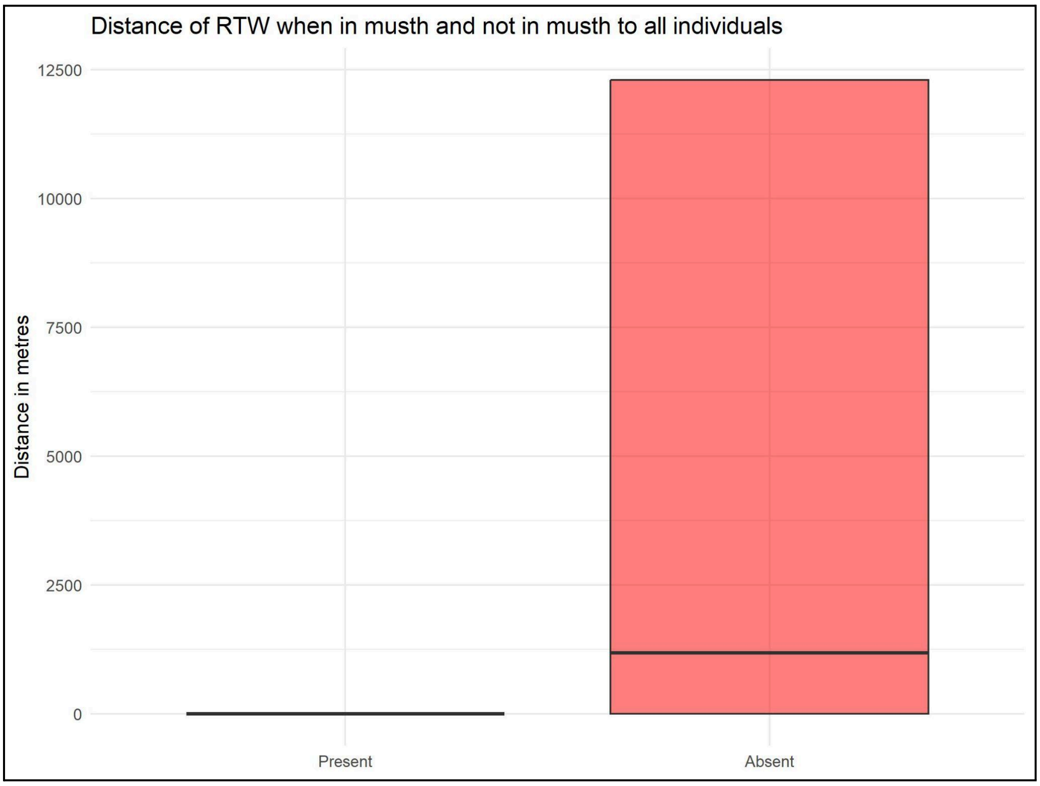


Fig62. The above figure shows the distance of RTW in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P=0.054

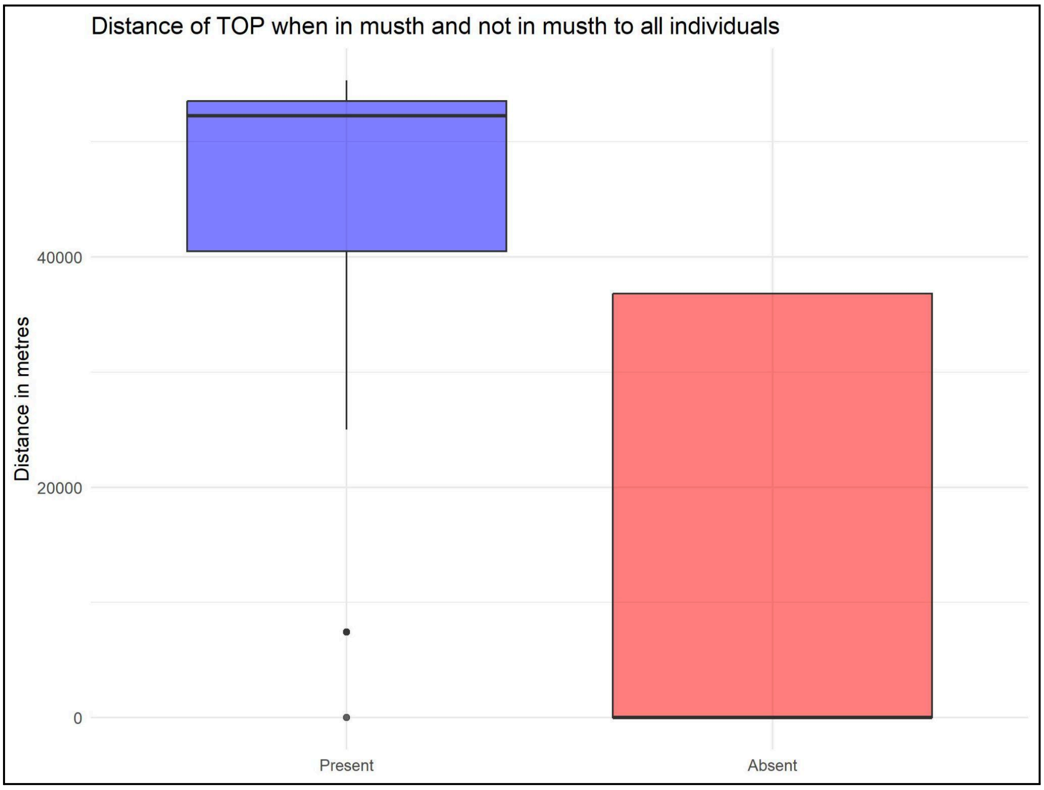


Fig63. The above figure shows the distance of TOP in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P<0.01

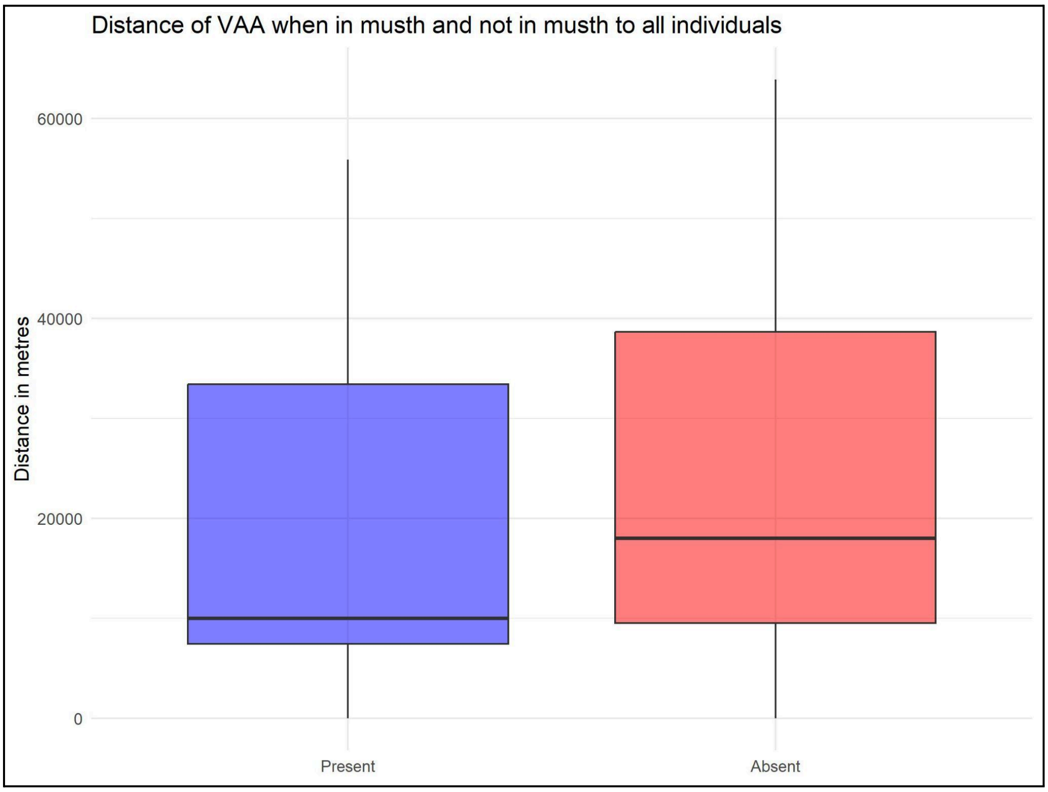


Fig64. The above figure shows the distance of VAA in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P=0.021

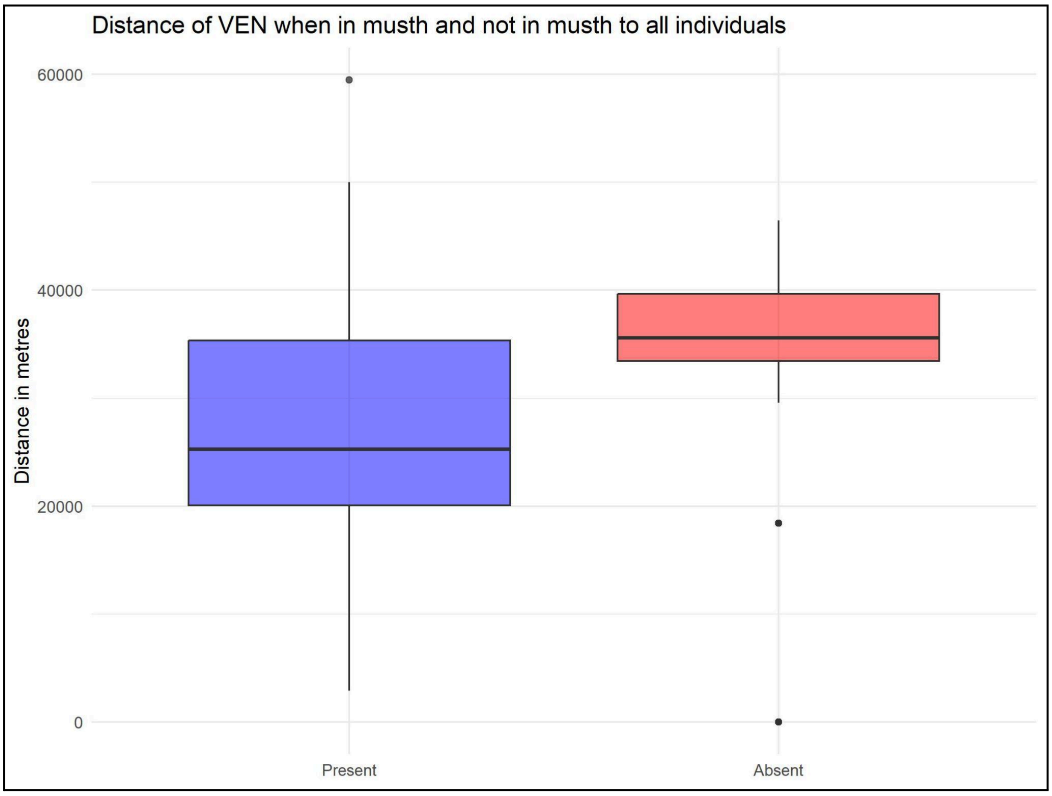


Fig65. The above figure shows the distance of VEN in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P<0.01

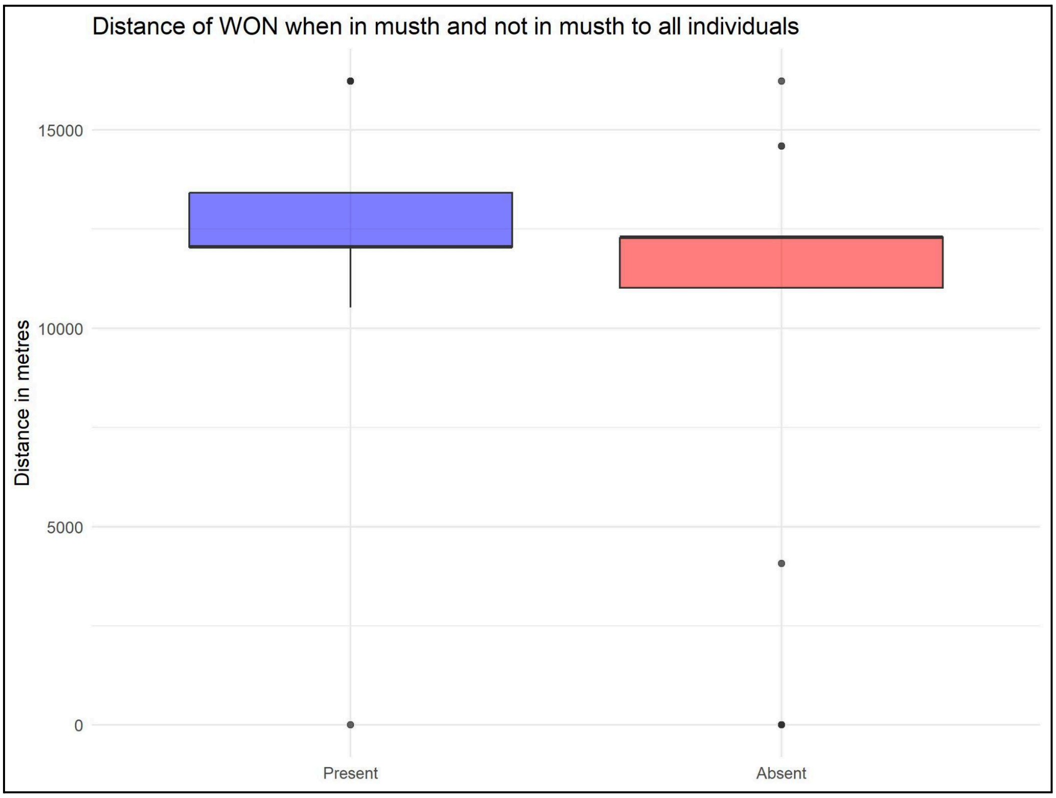


Fig66. The above figure shows the distance of WON in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)>Distance(Musth Absent). P=0.534

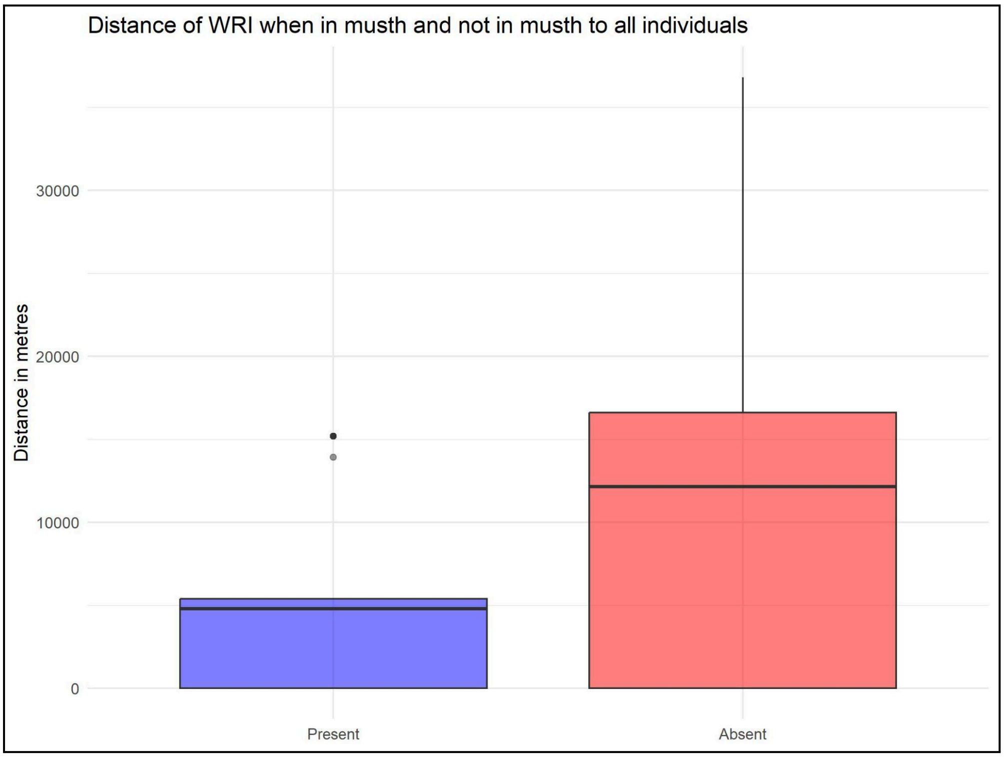


Fig67. The above figure shows the distance of WON in musth(blue) and not in musth(red) to all the other bulls in the study area. Here, we observe that Distance(Musth Present)<Distance(Musth Absent). P=0.03

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