Comparing acoustic properties, diel activity pattern and social representation of Golden Jackal *(Canis aureus)* in rural and urban habitat types

Submitted by

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Under the supervision of:

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Wildlife Institute of India

AcSIR

July 2026

DECLARATION

I hereby declare that the work conducted under the thesis entitled **"Comparing acoustic properties, diel activity pattern and social representation of Golden Jackal *(Canis aureus)* in rural and urban habitat types"**, is a record of original and independent research work done by me and subsequently submitted for the award of the degree of **Master's in Wildlife Science** at the **Academy of Scientific and Innovative Research (AcSIR)**. This research work has been carried out under the guidance and supervision of **Mr. Prashant Mahajan**, with co-supervision by **Dr. Bivash Pandav** of the Wildlife Institute of India, Dehradun, and **Ms. Seema Lokhandwala**, Principal Investigator, Elephant Acoustics Project. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding, and the particulars given in it are true to the best of my knowledge.

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CERTIFICATE

This is to certify that the thesis by **Ashutosh Bajpai** entitled **"Comparing acoustic properties, diel activity pattern and social representation of Golden Jackal *(Canis aureus)* in rural and urban habitat types"**, is an original work submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master's in Wildlife Science**.

Ashutosh Bajpai has completed one semester of research work, embodied in this thesis, under my guidance and supervision. The work presented in this thesis has not been submitted to any other university or Institute for the award of any degree, diploma or distinction.

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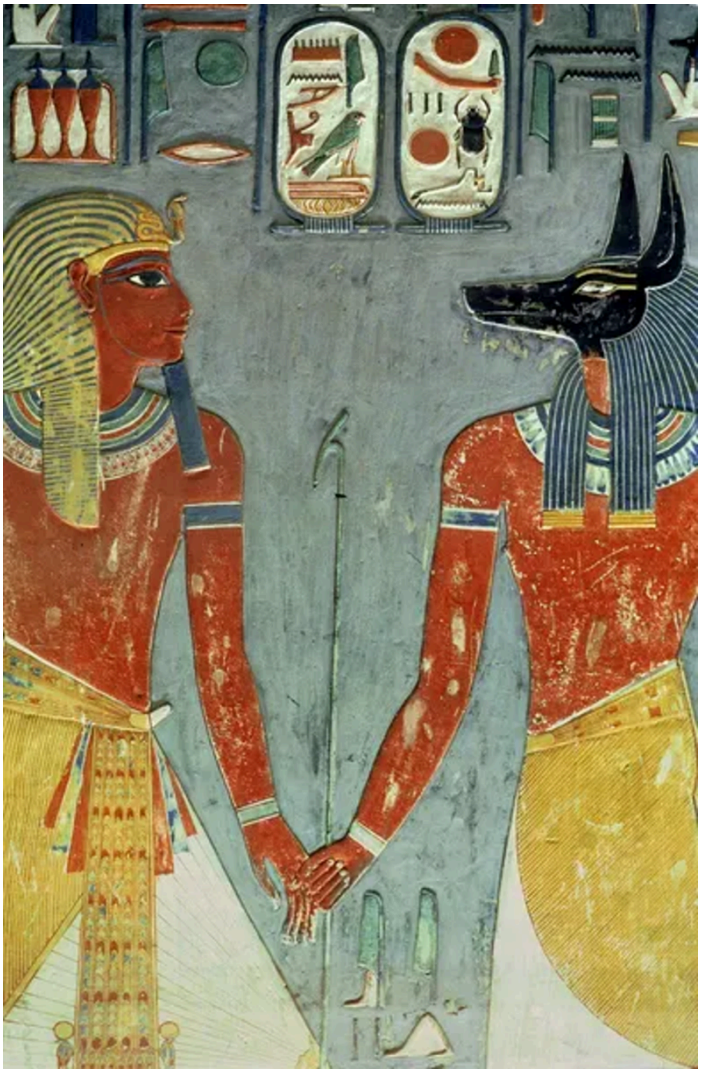
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"No group of wild mammals so universally captures the emotions of people world-wide than do wild canids. That emotion can be enchantment and fascination, but it can also be loathing, because the opportunism that is the hallmark of the dog family also leads them into conflict with humans."

~ From the book - The Biology and Conservation of Wild Canids
by David W. Macdonald and Claudio Sillero-Zubiri

1. Abstract

The selection pressures which an urban environment induces upon wild animals can lead to significant behavioural shifts over time. In this study, we attempted to understand the effect of urbanisation on acoustic properties and the diel activity pattern of golden jackals. We also explored the social representations of golden jackals in rural and urban environments. The Wildlife Institute of India's campus was the urban study area. Two ranges of Haridwar Forest Division and Gaindikhata village were the rural study area. We deployed passive acoustic monitoring devices for acoustic data collection, camera traps to understand diel activity patterns and interviews were taken to collect data on people's perception towards golden jackals. 129 vocalization events (urban-66 and rural 63) were used to compare acoustic parameters. Rural vocalisations were more spectrally brighter, acoustically elaborate and longer compared to urban vocalisations which were more spectrally darker, tonally denser and shorter. Rural jackals were found to be diurnal (59.6% day) while urban jackals were more nocturnal (71.6%). The most important finding from the prototypical quadrant matrix was that "dog-like appearance" was the most salient free listed item with Smith's Salience Index of 0.577 for rural subjects and 0.176 for urban. The urban subjects mostly ecology/wildlife and conservation professionals structured their representation around ecological and behavioural traits such as howling (0.152), scavenging behaviour (0.150), social animals (0.141) whereas rural respondents structured their representations around 'attacks poultry' (0.197), 'enters home/kitchen' (0.103), 'scavenger' (0.192). The study's findings suggest that golden jackals adapt to the stressors induced by urban respondents and have contrasting social representation in rural versus urban habitat type.

Keywords: golden jackals, acoustic ecology, diel activity pattern, social representation, habitat

2. Introduction

According to UNFPA's State of world population 2007 report, the world's urban population has swelled from 220 million to 2.8 billion over the 20th century. It is expected that by 2030, around 80% of the world's population will be living in urban areas (Lowry et al.,2013). The wildlife in urban areas is exposed to myriad anthropogenic stressors which can result in changes in the life history traits compared to their rural counterparts (Ditchkoff et al.,2006). The stressors such as noise, human activity, resource availability, hindrance in movement, exposure to different food resources can manifest in change of behaviour and life history traits. It could affect species ecology in terms of change in home range size, abundance, diet, time activity, vigilance, reproduction, disease, movement ecology and other core ecological aspects (Ritzel and Gallo, 2010). With rise in urban areas, the habitats are getting more fragmented, resulting in loss of habitat which leads to what is called biotic homogenisation in cities. But, urban areas also offer unique environments for some animals often called 'exploiters' or 'adapters' to exploit these novel conditions and adapt accordingly. The selection pressure which an urban environment applies on an animal is different to those in a more natural ecological setting which can lead to behaviour modifications such as change in time activity pattern to avoid human disturbance, change in diet due to human food provisioning, reduced fear of humans and increased boldness (Lowry et al.,2013). For example, the urban male song sparrows (Melospiza melodia) were found to be more bolder and territorial compared to their rural counterparts (Evans et al.,2010). This can also be explained by what is known as 'urban wildlife syndrome' which states that wild animals which are trying to adapt to urban stressors might show tendencies of heightened aggression and less fear of humans. In urban areas, the presence of artificial food resources in the form of garbage dumps and direct food provisioning by humans can shrink the home range and increase the population densities among mesocarnivores. In a study on raccoons (*Procyon lotor*) across an urbanisation gradient, the rural raccoons' home range size was three times larger than their urban counterparts (Prange et al.,2004).

Behaviour change in animals does not always need to be evolutionary. Non evolutionary adaptive changes in behaviour in animals can be broadly categorised into three types taking into account the time taken for the change to occur and its permanence (Lopez-Sepulcre and Kokko, 2012; McDonnell and Hahs, 2015). First are the regulatory responses such as changes in flight initiation distance or alert behaviour. Second are the acclimatory responses which include change in territoriality or changes in diet. While the third type of behavioural response such as change in bill size comes under developmental responses which can often lead to evolutionary changes in the animal. Ritzel and Gallo, 2020 undertook a systematic literature review in an attempt to understand the type of behaviour changes in urban mammals found acclimation to be the most common type of adaptive response. Behaviour change such as decrease in home range was the most common adaptive response followed by increase in nocturnality and change in diet preference. Whereas change in vigilance and decrease in flight initiation distance were the two most common regulatory responses. Increase in boldness and exploratory behaviour were found to be the most common type of developmental response.

2.1 Acoustic adaptations in response to urbanisation

Acoustic communication is an important aspect of the social life of animals. The success of animal communication depends highly on the environmental factors, especially ambient noise which can mask the signals and limit the distance it can travel (Hu and Cardosa 2010). The species which depend on vocalisation to communicate are impacted negatively by higher noise pollution in urban areas (Slabbekoorn and Peet 2003). Animals resort to various methods to overcome the acoustic disturbances induced by urban environments one such method is to raise the minimum frequency as anthropogenic noise normally hampers low frequency sounds which are more prone to get masked. A study on 12 bird species in urban and nonurban settings in Australia found an increase in average minimum frequency in urban birds compared to the nonurban counterparts. Instead of adjusting the entire vocalisation , the birds often chose to adjust minimum frequency. This also adds up in support of the hypothesis that bird species operating on higher frequencies are less affected by ambient urban noise (Hu and Cardosa 2010). Another way in which species tend to overcome the noise pollution in

urban areas is known as the Lombard effect where animals increase the vocal amplitude of the call to mitigate the increase in anthropogenic noise (Brumm 2004). Also longer signals are prone to more degradation due to echo effects which can be problematic in highly structured urban areas (Wiley 1982).

2.2 Temporal adaptations in response to urbanisation

When it comes to wildlife conservation and management, the focus has primarily been on the species' spatial ecology whereas temporal behaviour goes under the radar. Temporal dynamics of a species are closely linked with the "spatial characteristics" of the environment a species resides in. Temporal variation in diel activity patterns is one of the most common behavioural adaptations which a species opts to evade urban stressors.Urbanisation can affect the temporal behaviour of different species in different ways. Gallo et al.,2022 in their study on temporal behaviour of 8 mammal species across 10 cities in the US found significant changes in diel activity in response to increased human population. Different species showed different adaptations to increasing urbanisation where coyotes *(Canis latrans)* were found to be more active during nighttime with increase in human population density but it was opposite for white-tailed deer *(Odocoileus virginianus)* which showed decrease in nocturnality with increase in human population density.

Gaynor et al., 2018 conducted a meta-analysis of 62 medium to large bodied mammals using 76 studies spanning over six continents to understand how animals react to increasing human impact. They called humans as a diurnal apex "super predator" driving animals towards more nocturnality.

2.3 Social Representation Theory

The social representation theory developed by French social psychologist, Serge Moscovici helps us in understanding the "common sense" knowledge which is built, shared and communicated in the society and the different social groups and how it conjoins the practical knowledge with scientific knowledge. SRT works by understanding shared cognitions around ideas like "values, beliefs, images and

practices" which holds the social group together. Moscovici emphasises that representations are shaped primarily through interaction within a social context and not just individual thought. This is where he diverges from Durkheim, who treated representations as fairly fixed and society-wide. Moscovici instead argues that in modern societies, many different social representations exist at once, held by different groups rather than society as a single unit. Because of this, Moscovici prefers the term "social" over "collective" as it better fits how fragmented and fast-changing modern societies are. It combines a social angle with a cognitive one, which helps explain the mixed and sometimes contradictory ways people relate to things like their natural environment. SRs aren't simple or one-dimensional; they rather include values, emotions, attitudes, and practices all mixed together (Abric, 1996). Because of this mix, contradictory elements can coexist within the same representation, a phenomenon Moscovici calls "cognitive polyphasia." It explains how different, even conflicting, types of knowledge can exist side-by-side within the same person or group. Compared to the related concept of "attitudes," SRs offer a fuller picture. Attitudes only capture fragments of how people view something, whereas SRs function more like complete belief systems with their own internal logic.

Structurally, Abric (1993) splits SRs into two parts: a central core, which is stable and shared across the group (shaped by collective memory and group norms), and peripheral elements, which are more flexible and respond to changing situations. This flexibility allows the group to remain diverse even while sharing a stable core. New ideas that show up at the periphery may fade quickly — or, over time, some can work their way into the central core.

2.4 Golden Jackal- introduction of the model species

The Golden Jackal (*Canis aureus,* Linneaus 1758) is a widely distributed, medium sized canid. It occurs in northern and eastern Africa, south-eastern Europe, the Middle East and extends eastwards into central, southern and southeast Asia as far south as Sri Lanka and Thailand. It is a Least Concern species as per the IUCN Red List Assessment. Population is expected around 80,000 for the Indian sub-continent (Hoffman et al.2018). Three species of Jackals are found worldwide: the **Golden Jackal**

(Canis aureus), **Black Backed Jackal** *(Lupulella mesomelas)* and **Side Striped Jackal** *(Lupulella adustus)*. The earlier considered Golden Jackal population in Northern Africa was found to be a distinct species, that is, **African (Golden) Wolf** *(Canis lupaster)* in 2015 (Koepfli et al.2015). Information about jackals' vocal behaviour is still scanty. As in other canid species, the golden jackal exhibits a complex vocalization repertoire (Jhala and Moehlman 2004), including single and group howls. These calls mainly serve to maintain group cohesion and play a role in finding a reproductive partner and in territorial defence. They are usually more frequent in the reproductive period (Jaeger et al. 1996) and in areas with high population density (Giannatos 2004; Jaeger et al. 2007). Giannatos et al. (2005) reports that solitary individuals vocalize less frequently than those in a pack, possibly due to their young age or to their attempt to avoid fights with resident packs. Other than howls, the vocal repertoire includes hisses, huffs and roars and a species-specific alarm call elicited by the presence of other large carnivores as wolves, hyenas and tigers. Golden Jackals are monogamous and breed during winters in the Indian subcontinent. Like most of the canids, they are secondary excavators and use the borrows opportunistically. The breeding phase lasts for around 40 days and both male and female contribute to rearing the pups together, sometimes 'Helpers' which are from the previous litter also help their parents in pup rearing. Golden jackals' wide distribution and adaptability in terms of habitat and dietary habits have been studied widely but vocalization is one such aspect which has not been looked at scientifically (Comazzi et al. 2016).

3. Aim and Objectives

AIM: To understand the behavioural adaptations (acoustic and temporal) and social representation of Golden Jackal in rural and urban habitat type

OBJECTIVES:

1. To compare acoustic parameters of Golden Jackal vocalisation events between rural and urban habitat type.

2. To compare diel activity pattern of Golden Jackal between rural and urban habitat type.
   a. Does each group (rural and urban) have a structured activity pattern?
   a. Do rural and urban populations differ in their diel activity?

3. To compare social representations of Golden Jackal between rural and urban population (wildlife and conservation professionals).

4. Study Area

The rural study area was based in Shyampur and Chidyapur ranges of Haridwar Forest Division and Gaindikhata village. Gaindikhata is a village in the Bahadarabad block of the Haridwar district, Uttarakhand. It is located roughly 20 km from Haridwar city, it serves as an important rural and tribal cluster, known for its Van Gujjar community. The total population of Gaindikhata is 2817 (Census 2011) and the number of houses is 549. In 2003 due to the persistent efforts finally the initiative of the forest department to relocate the Van Gujjar community which resided inside the Rajaji National Park bore success. In total, 193 gujjar families with around 3,000 livestock from within Chilla range were resettled in the Chidiyapur range of Haridwar Forest Division (Harihar et al.,2009).

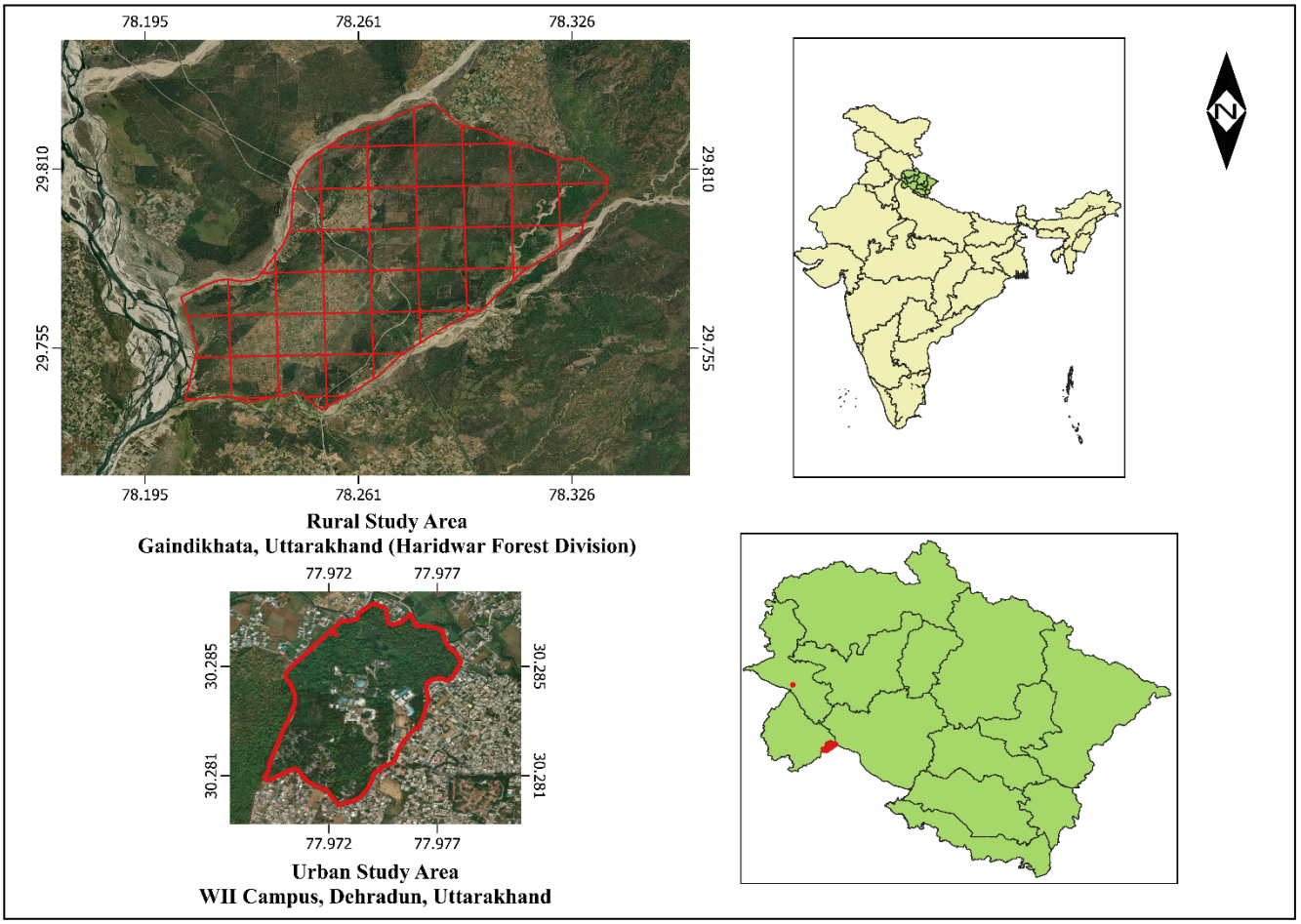


Figure 1: Study Area Map

The Haridwar forest division (29°58′6.02″N,78° 13′9.82″E) is located in Uttarakhand and falls under the Gangetic plains biogeographic zone (Rodgers & Panwar, 1988). The area receives most rainfall between mid-June and September, followed by the arrival of winter from November through February and the dry season between March and May. November is the driest month with just 4mm of rain. Highest precipitation is seen in July, with an average of 375 mm.

The principal vegetation in the region includes tropical dry and moist deciduous forests, scrub vegetation, alluvial grasslands and forest plantations. The vegetation communities include Sal (*Shorea robusta*) dominated forests along, Sal-mixed forests of *Shorea robusta, Mallotus philippensis & Lagerstroemia parviflora*, riverine forests of *Acacia catechu, Dalbergia sisoo & Syzygium cumini* and mixed forests of *Lagerstroemia parviflora, Holoptelea integrifolia, Ehretia laevis, Adina cordifolia* & *Anogeissus latifolia.*

The vegetation is natural and semi-natural represented by a mosaic of natural scrub, woodland, various successional stages of Shorea robusta forest including stream bank vegetation and grassy banks. There are a total of 556 plant species comprising 438 species of herbs and climbers including 12 species of pteridophytes, 54 species of trees, 64 species of shrubs and lianas. Angiosperms are distributed over 99 families with 368 genera. Large scale plantations were carried out in the 1960s to meet the increasing demand of timber which replaced the Sal dominated mixed forests. Softwood species such as *Eucalyptus* spp., *Ailanthus excelsa*, *Populus ciliata* and hardwood species like *Acacia catechu*, *Dalbergia sissoo, Tectona grandis* were planted extensively (Johnsingh and Negi, 2003).

The Wildlife Institute of India Campus harbours a total of 616 plant species comprised of 58 trees, 65 shrubs (including lianas), 357 herbs and climbers (vines) including 9 species of pteridophytes, 71 grasses and 27 sedges belonging to 107 families (99 Angiosperm and 8 Pteridophyte) with 384 genus (375 Angiosperm and 9 Pteridophyte). Of the total 616 plant species, 94% species are in the wild and

6% species are planted. The faunal diversity of the campus is also rich, Birds: 310 species belonging to 49 families, Amphibians: 11 species belonging to 4 families, Butterflies: 90 species belonging to 5 families, Moths: 16 species belonging to 7 families, Reptiles: 22 species belonging to 7 families, Spiders: 17 species belonging to 6 families and mammals: 17 species belonging to 14 families.

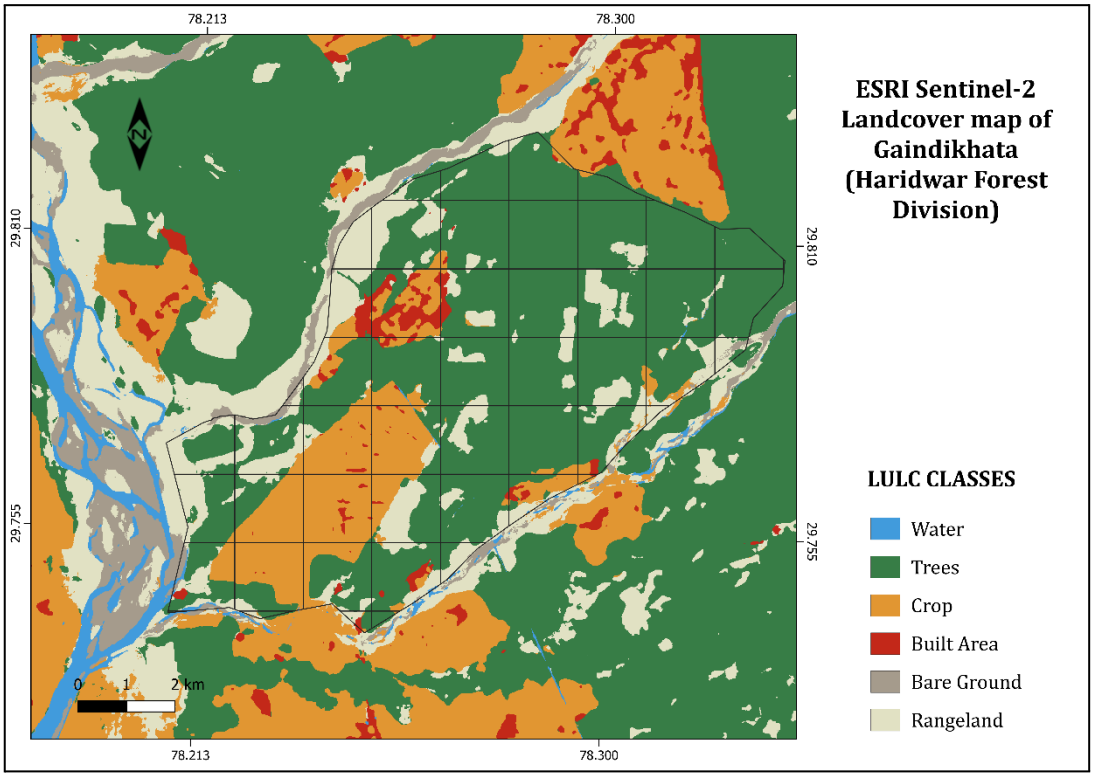


Figure 2: ESRI Sentinel-2 landcover map of rural study area

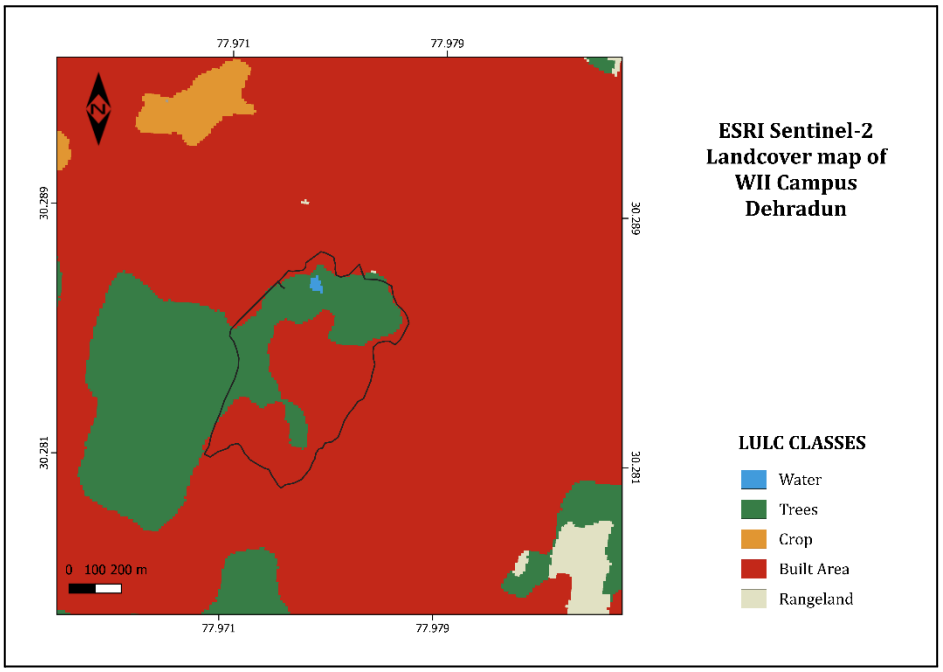


Figure 3: ESRI Sentinel-2 landcover map of urban study area

5. Materials and Methods

5.1 Bioacoustics

5.1.1 Acoustic Data Collection

The collection of acoustic data was carried out using automatic recording units (ARUs) which is a well-established practice for passive acoustic monitoring. We used the AudioMoth (version 1.2.0) by Open Acoustic Devices. For the rural study area, the ARUs were deployed in 36 grids of 2 sq km each, covering a total area of 72 sq km. The ARUs were placed in the center of the grid paired with camera traps and were operational from late March till mid-May, 2026. Each ARU was programmed to record for 12 hours everyday from 06:00 PM in the evening till 06:00 AM in the morning [12:30-00:30 (UTC)]. The configuration settings for AudioMoth were as follows: the firmware version on which the AudioMoths were operational was AudioMoth-Firmware-Basic (1.10.1) with sample rate of 48 kHz and medium gain. The batteries were changed every two weeks. The settings were kept similar for the ARUs placed in the urban study area where the ARUs were placed opportunistically to minimise anthropogenic noise.

5.1.2 Acoustic Data Processing

The 12-hour audio files were generated per device per day. They were scanned for Golden Jackal vocalisation events using Raven Pro 1.6.5 (Cornell Lab of Ornithology). Hann windows were used at the rate of 8878 samples on 7.78 Hz on 3dB Filter Bandwidth. The vocalisation events were clipped and saved in the respective habitat folder. In total, 129 vocalisation events were used for further analysis. 66 from urban and 63 from rural. The files were then transported to Praat (v 6.4.67) to extract 75 acoustic features with pitch floor (200Hz) and pitch ceiling (3500hz). It included parameters like fundamental frequency, abrupt, formants, intensity, HNR (Harmonics to Noise ratio), jitter, shimmer, spectral moments and MFCCs (Mel Frequency Cepstral Coefficients).

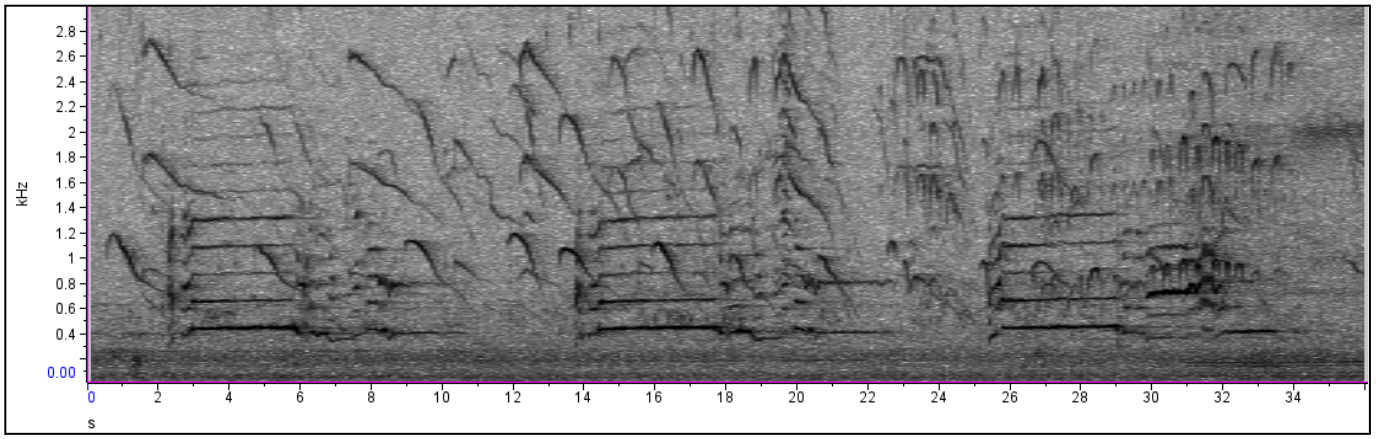


Figure 4: A spectrogram of jackal vocalization event

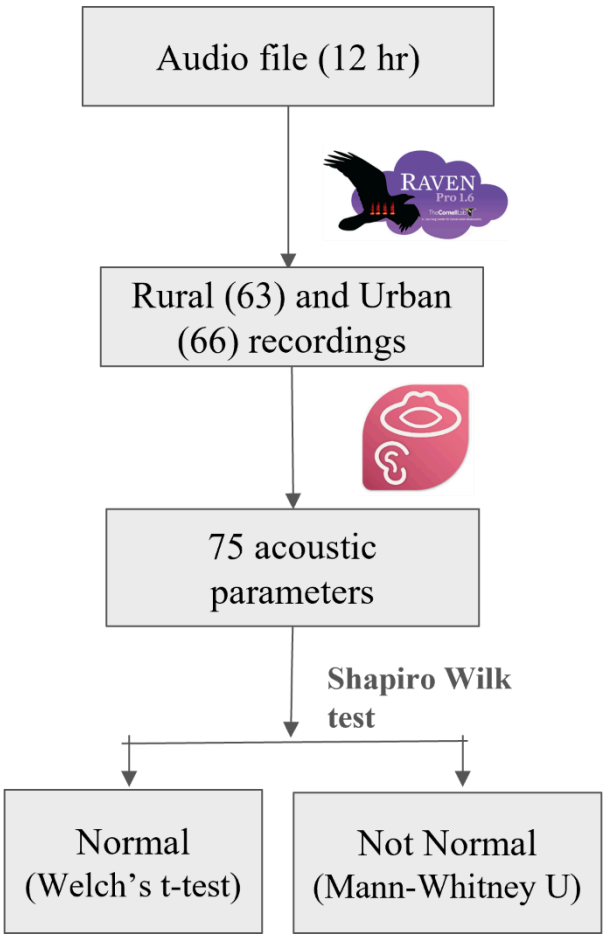


Figure 5: Analytical method flowchart for Objective 1

5.1.3 Bioacoustic Analyses

After extracting the acoustic parameters in Praat, the Shapiro Wilk test was used to check the normality. The parameters which were normal were compared between rural and urban study areas using Welch's t-test whereas the ones which were not normal were compared using Wilcoxon

Rank-Sum (Mann-Whitney). Cohen's d was calculated to know the effect size and gauge practical meaningfulness. Principal Component analysis (PCA) was done on 12 bioacoustics variables to understand if there is multivariate acoustic differentiation between rural and urban Golden Jackal population. The 12 variables selected were chosen from five broad acoustic domains.

Table 1: 12 Acoustic Parameters and their respective acoustic domain

Acoustic domain	**Acoustic Parameters**
Spectral shape	Spectral center of gravity, spectral skewness
Vocal timbre	MFCC1, MFCC3 and MFCC8
Voice quality	HNR mean, jitter local, shimmer local
Vocal tract structure	F4 mean
Temporal structure	Duration
Pitch variability	abrupt_f0_ts005
Sound intensity	Intensity mean

The selection of principal components was based on the Kaiser criterion (eigenvalue >1). Loadings >0.3 were used to interpret the results. All the analysis was done in RStudio using packages like ggplot2, factoextra and patchwork.

5.2 Camera Trap

5.2.1 Camera Data Collection

The study design for camera trapping was kept the same as that of acoustic data collection. In the rural study area, the Browning Trail cameras were deployed in the center of all 36 grids of 2 sq km each, spanning over 72 sq km. The camera traps were programmed to take videos of 10 seconds with one second capture delay. The camera traps were active in both the study areas for 45 days from late March till mid of May, 2026.

5.2.2 Camera Data Processing

The images were sorted using habitat type (rural and urban) and date and time were extracted. The captures were labelled independent if there was a difference of 30 minutes or more between two captures. The sunrise and sunset time were obtained for dates when the camera traps were operational. The time block matrix was created placing each capture into four time blocks which were Dawn, Day, Dusk and Night. Dawn was categorized as time 30 minutes before and 60 minutes after sunrise. The day was 60 minutes after sunrise and 30 minutes before sunset. Dusk was 30 minutes before till 60 minutes after sunset and night was 60 minutes after sunset till 30 minutes before sunrise.

Table 2 : Time block matrix

Dawn	30 minutes before and 60 minutes after sunrise
Day	60 minutes after sunrise and 30 minutes before sunset
Dusk	30 minutes before till 60 minutes after sunset
Night	60 minutes after sunset till 30 minutes before sunrise

5.2.3 Camera Trap Data Analysis

All the analyses were done using the ‘circular’ package in RStudio (version 4.5.0). Circular mean, mean resultant length, kappa and circular standard deviation were calculated for two habitat types. Kuiper’s one sample test was performed to understand if each habitat group had a structured

(non-random) time activity pattern or were distributed uniformly. The test was chosen because it takes into account multi modal departures from uniformity which Rayleigh test fails at. Watson's Two sample test of Homogeneity (U^2) was performed to understand if both rural and urban samples were drawn from the same circular distribution. To understand the temporal overlap between two groups, Kernel Density Estimation was carried out to quantify how much the two activity patterns coincide on a 0 to 1 scale. Dhat1 estimator was used for coefficient of overlap as the smaller (rural=47) of the two samples was less than 50. To understand the association between habitat type and usage of time block, we performed Fisher's Exact Test (Monte Carlo, B=100,000) over Chi-square test (X^2) as multiple cells in time block matrix have frequency less than 5 and over Fisher's Exact Test (Standard) as it can only handle 2*2 matrix whereas our matrix constituted of 2*4 rows and columns. Cramer's V was calculated to gauge the practical significance.



Figure 6: Field setup of Audiomoth and Camera trap

5.3 Socio-ecological Survey

5.3.1 Survey Data Collection

The questionnaire survey based on the Social Representation Theory framework was conducted for rural subjects in physical mode in the months of April and May, 2026. The interview was conducted in almost all the grids with human habitation ensuring spatial coverage. The respondents were informed about the scope of the study and verbal consent was taken before starting the interviews. The interviews were primarily taken in Hindi and Gujari assisted by a local field assistant. The responses were documented using printed questionnaire forms and all qualitative responses were recorded verbatim. Efforts were made to attain equal representation of all age groups and gender.

For the urban audience, the main target group was wildlife, ecology and conservation professionals. The questionnaire was circulated to the subjects using Google form. The identity of the respondent was kept anonymous. Interviews were started by knowing respondents' profile like age, gender, education, livelihood and also their interactions with Golden Jackal and source of their knowledge. Moving on to the free-listing section, the respondents were told a word in our case ‘Golden Jackal’- the name was told in Hindi and Gujari (Gedd, Gidad or Siyar). The respondents were encouraged to tell all the words/phrases or sentences which come to their mind in exact order without censoring.

5.3.2 Survey Data Processing

The rural survey data which was documented in hard copies was entered into Google Sheets. The questions in which the answers were recorded verbatim in Hindi/Gujari were translated into English. The words/phrases obtained during free listing exercise were further coded into broader themes like physical characteristics, behavioural traits, perception, mythology, diet, etc. The items in the attitude scale were reverse coded wherever required.

5.3.3 Socio-ecological Data Analyses

The spontaneous ideas and associations which the rural respondents had about Golden Jackal were understood using free listing. After coding the words and phrases and ideas into different bins, each item was analysed using: (a) Frequency- the number of respondents mentioning the item (b) Mean rank- the average position the item appeared in respondents lists and (c) Salience which tells the relative importance of the item taking into account both frequency and rank.

A quadrant matrix was created which combined both frequency and mean rank to identify the structure of social representation. This table explains the four quadrants used in prototypicality analysis of free-listing data. It provides a structured view of rural respondents.

Table 3: Four quadrants in prototypicality matrix

Quadrant	**Meaning**	**Interpretation**
Core / Prototype	High frequency + low mean rank	Most central, stable, and widely shared ideas. These items are mentioned by many respondents and recalled early, indicating strong cognitive salience.
First Periphery	High frequency + high mean rank	Commonly shared ideas, but less immediately recalled. These items support and contextualise the core representation.
Contrast Zone	Low frequency + low mean rank	Important ideas for a smaller subgroup of respondents. These items may reflect specific experiences, local contexts, or minority viewpoints.
Second Periphery	Low frequency + high mean rank	Less common and less central ideas. These items are weakly shared and usually represent additional or marginal associations.

Frequency refers to the number of respondents who mentioned an item; mean rank refers to the average position at which the item appeared in respondents' lists. Lower mean-rank values indicate earlier recall and stronger salience.

The attitude scale measures respondents' acceptance, tolerance, fear and support for conservation of the Golden Jackal. The bar plots were used to interpret the attitude trends towards the species between rural and urban population. The semantic differential profile was developed by Charles Osgood explaining three primary dimensions which are Evaluation, Potency and Activity. It works by making respondents place ideas across the bipolar spectrum.

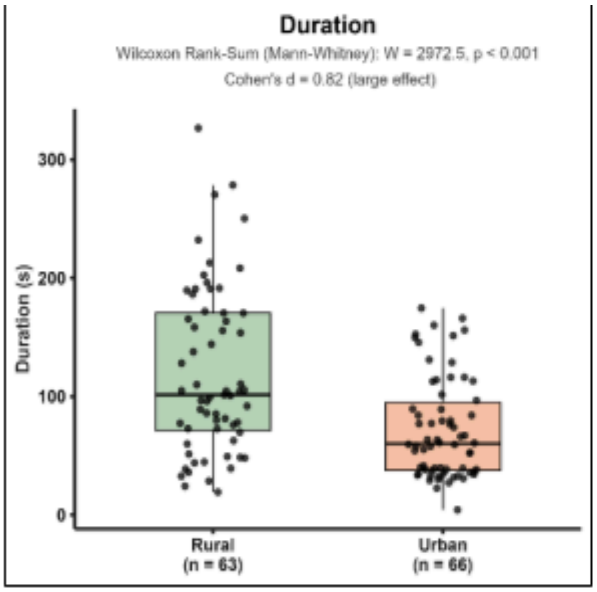
6. Results

6.1 Bioacoustics

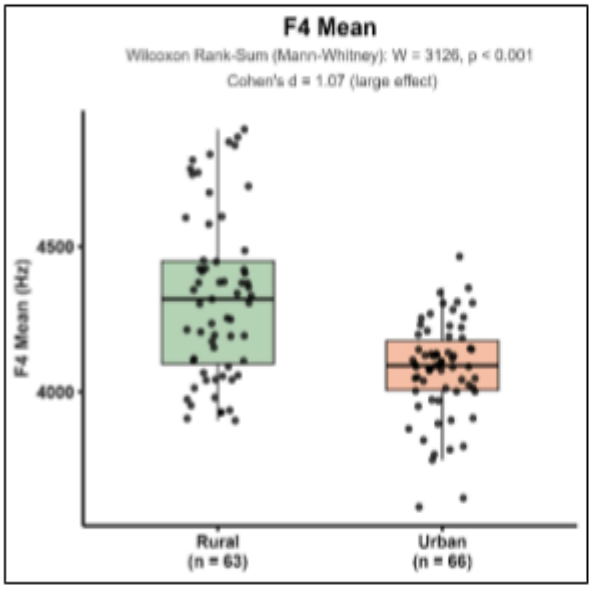
In total, 129 Golden Jackal vocalisation events were found, 66 from urban and 63 from the rural study area. Out of 72 parameters which were extracted only 7 had normal distribution whereas the rest 65 parameters were not normal.

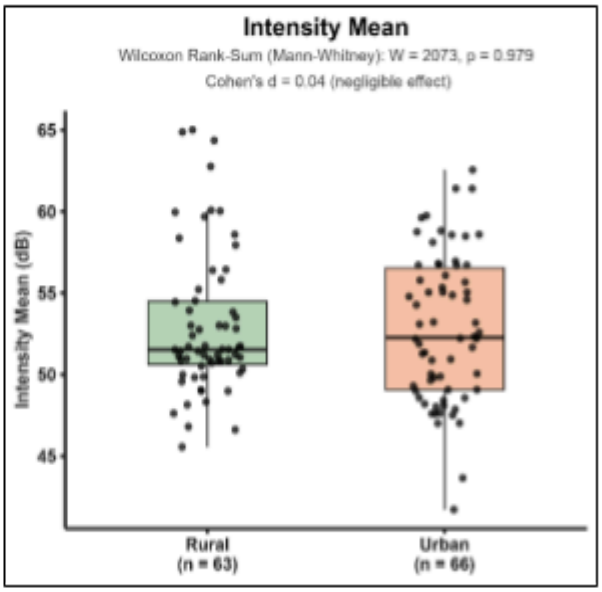
The duration of vocalisation events was longer in rural compared to urban. The mean rural call duration (120.14 ± 70.34 s) was higher than urban (72.22 ± 42.56 s). There was a significant difference in the Spectral Centroid (spectral energy). It was higher in rural (4164.23 ± 2321.4 Hz) than urban (1933.64 ± 826.87 Hz). The local shimmer (mean absolute amplitude difference between consecutive vocal periods) was found to be more in urban habitat. The urban local shimmer (0.21 ± 0.02) compared to rural local shimmer (0.22 ± 0.01). The MFCC3 mean was higher for rural (46.47 ± 32.29) than urban (-20.85 ± 47.45).

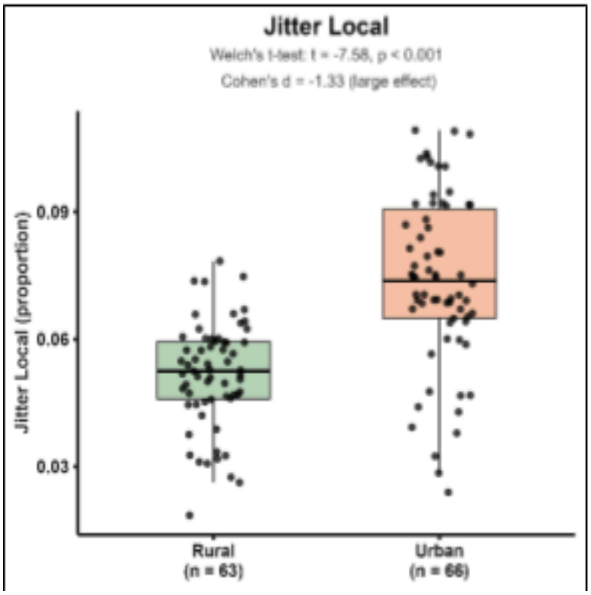
The mean frequency of the fourth formant was higher for rural (4326.33 ± 281.94 Hz) compared to urban (4079.35 ± 165.29 Hz). The MFCC8 mean was higher for urban (13.24 ± 15.54) than rural (-20.65 ± 18.46). The MFCC1 mean was higher for urban (92.46 ± 45.91) than rural (8.91 ± 61.45). The mean spectral skewness was higher for urban (4.91 ± 2.82) compared to rural (2.50 ± 1.83). The mean Harmonics to Noise ratio was higher in urban areas (6.96 ± 3.04 dB) compared to rural (4.65 ± 2.24 dB). Local jitter was higher for urban areas (0.07 ± 0.02) compared to rural (0.05 ± 0.01). Intensity mean was found to be not significantly different between rural and urban habitat types.

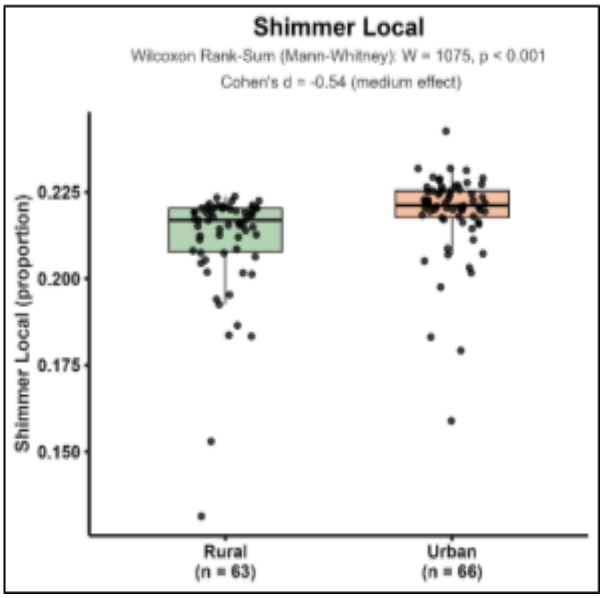

Duration
Wilcoxon Rank-Sum (Mann-Whitney): W = 2972.5, p < 0.001
Cohen's d = 0.82 (large effect)
Duration (s)
300
200
100
0
Rural
(n = 63)
Urban
(n = 66)


HNR Mean
Wilcoxon Rank-Sum (Mann-Whitney): W = 1067, p < 0.001
Cohen's d = -0.86 (large effect)
HNR Mean (dB)
15
10
5
0
Rural
(n = 63)
Urban
(n = 66)


F4 Mean
Wilcoxon Rank-Sum (Mann-Whitney): W = 3126, p < 0.001
Cohen's d = 1.07 (large effect)
F4 Mean (Hz)
4500
4000
Rural
(n = 63)
Urban
(n = 66)


Intensity Mean
Wilcoxon Rank-Sum (Mann-Whitney): W = 2073, p = 0.979
Cohen's d = 0.04 (negligible effect)
Intensity Mean (dB)
65
60
55
50
45
Rural
(n = 63)
Urban
(n = 66)


Jitter Local
Welch's t-test: t = -7.58, p < 0.001
Cohen's d = -1.33 (large effect)
Jitter Local (proportion)
0.09
0.06
0.03
Rural
(n = 63)
Urban
(n = 66)


Shimmer Local
Wilcoxon Rank-Sum (Mann-Whitney): W = 1075, p < 0.001
Cohen's d = -0.54 (medium effect)
Shimmer Local (proportion)
0.225
0.200
0.175
0.150
Rural
(n = 63)
Urban
(n = 66)


Spectral Centroid
Wilcoxon Rank-Sum (Mann-Whitney): W = 3449, p < 0.001
Cohen's d = 1.28 (large effect)


Spectral Skewness
Wilcoxon Rank-Sum (Mann-Whitney): W = 697, p < 0.001
Cohen's d = -1.01 (large effect)

Table 4: Significance, p value and Cohen's d of parameters

Parameter	Rural mean	Urban mean	Normally Distributed	Test	Test statistic	p value	Cohen's d	Significant
Duration	120.14 ± 70.34 s	72.22 ± 42.56 s	No	Mann-Whitney U	2972.5	<0.001	0.82	Yes
HNR mean	4.65 ± 2.24 dB	6.96 ± 3.04 dB	No	Mann-Whitney U	1067	<0.001	-0.86	Yes
F4 mean	4326.33 ± 281.94 Hz	4079.35 ± 165.29 Hz	No	Mann-Whitney U	3126	<0.001	1.07	Yes
MFCC1 mean	8.91 ± 61.45	92.46 ± 45.91	No	Mann-Whitney U	531	<0.001	-1.54	Yes
MFCC3 mean	46.47 ± 32.29	-20.85 ± 47.45	No	Mann-Whitney U	3705	<0.001	1.66	Yes
MFCC8 mean	-20.65 ± 18.46	13.24 ± 15.54	No	Mann-Whitney U	354	<0.001	-1.99	Yes
Jitter local	0.05 ± 0.01	0.07 ± 0.02	Yes	Welch's t-test	-7.58	<0.001	-1.33	Yes
Shimmer local	0.22 ± 0.01	0.21 ± 0.02	No	Mann-Whitney U	1075	<0.001	-0.54	Yes
Spectral Centroid	4164.23 ± 2321.4 Hz	1933.64 ± 826.87 Hz	No	Mann-Whitney U	3449	<0.001	1.28	Yes
Spectral Skewness	2.50 ± 1.83	4.91 ± 2.82	No	Mann-Whitney U	697	<0.001	-1.01	Yes
abrupt_f0_ts005	862.02 ± 634.21	518.53 ± 311.16	No	Mann-Whitney U	2673	0.005	0.69	Yes
Intensity mean	53.01 ± 4.43 dB	52.81± 4.54 dB	No	Mann-Whitney U	2073	0.98	0.04	No

Principal Component Analysis

PCA was run on 129 Golden Jackal vocalisation events using 12 bioacoustic variables. The results were successful in showing multivariate acoustic differentiation between rural and urban habitat type. Five principal components with eigenvalues more than 1 (based on Kaiser criterion) explained 80.5% total variance. Whereas the first three principal components explained 62.6% of cumulative variance. (PC1 (35.2%), PC2 (14.7%) and PC3 (12.7%)).

PC1 significant loadings included mfcc1_mean (+0.44), spec_skewness_mean (+0.36), spec_cog_mean (-0.40), mfcc3_mean (-0.35) and f4_mean (-0.30). PC2 significant loadings included shimmer_local (-0.56), jitter_local (-0.50), abrupt_f0_ts005 (-0.40) and intensity_mean (+0.32). PC3 significant loadings included intensity_mean (+0.53), duration (-0.42), shimmer_local (+0.40) and mfcc8_mean (-0.36).
Habitat had a significant effect on multivariate acoustic structure (PERMANOVA: pseudo-$F_{1,127} = 71.99$, $R^2 = 0.362$, $p < 0.0001$)

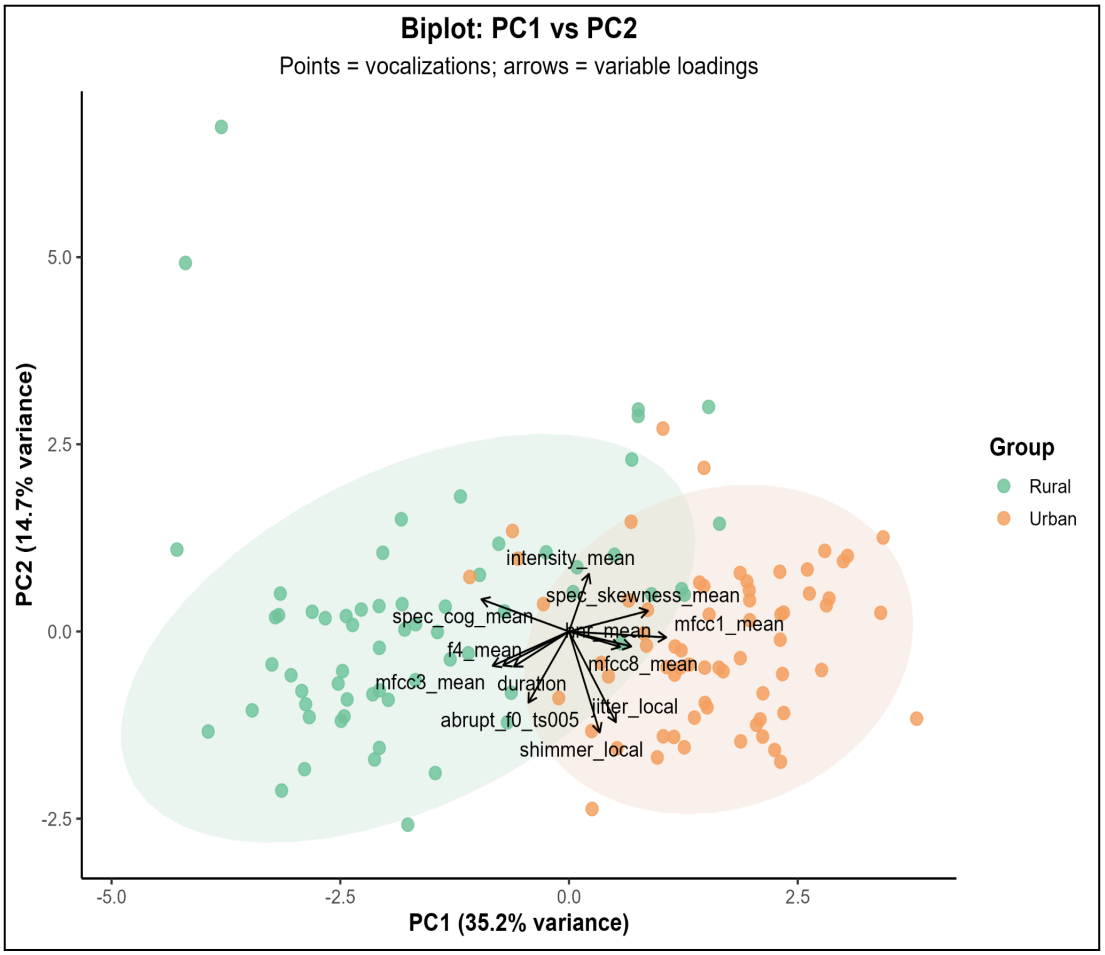


Figure 9: PCA biplot of golden jackal vocalizations in rural and urban landscapes

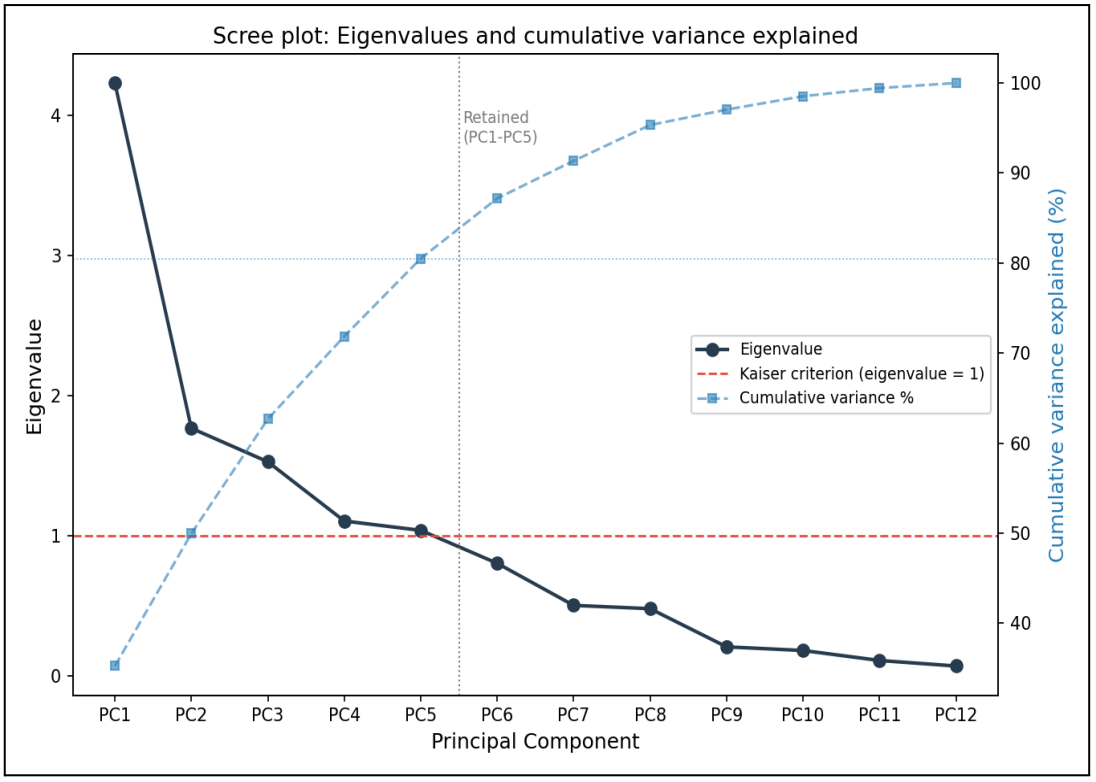


Figure 10: Scree Plot – Eigen values and cumulative variance

Table 5: PCA Loadings

Variable	PC1	PC2	PC3	PC4	PC5
mfcc8_mean	0.28	-0.08	-0.28	**-0.36**	-0.02
mfcc3_mean	**-0.35**	-0.19	-0.12	-0.03	**-0.37**
mfcc1_mean	**0.44**	-0.03	0.13	-0.09	0.10
jitter_local	0.21	**-0.50**	-0.17	0.24	-0.07
spec_cog_mean	**-0.40**	0.18	-0.17	0.17	0.07
spec_skewness_mean	**0.36**	0.12	**0.41**	0.16	-0.13
f4_mean	**-0.30**	-0.19	0.13	0.22	**-0.49**
hnr_mean	0.23	-0.09	0.15	-0.29	**-0.66**
duration	-0.25	-0.20	**0.42**	**-0.42**	0.27
shimmer_local	0.14	**-0.56**	-0.13	**0.40**	0.21
intensity_mean	0.09	**0.32**	**0.35**	**0.53**	-0.05
abrupt_f0_ts005	-0.19	**-0.40**	**0.55**	-0.06	0.16

6.2 Camera Trap

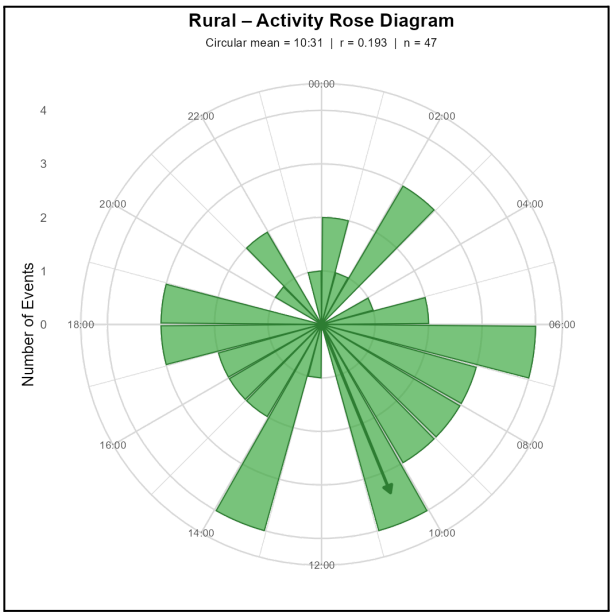
After processing the camera trap data, we got 149 independent photo captures of Golden Jackal across both the study areas. There were 47 independent photo captures in the rural study area whereas in the urban study area there were 102 independent photo captures.

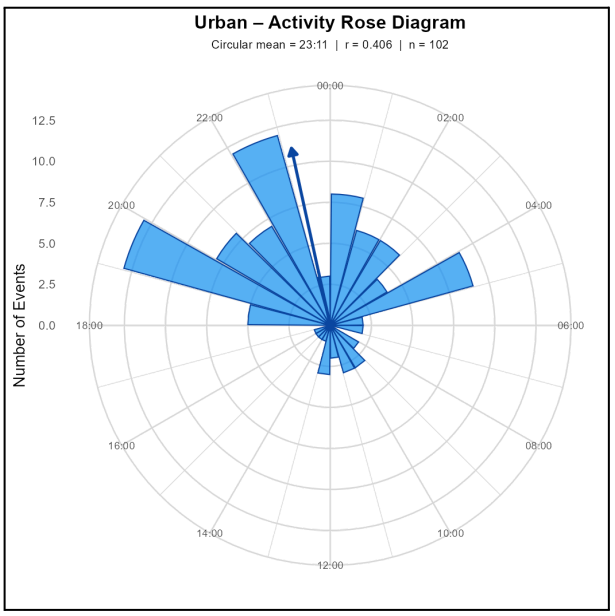
Table 6: Matrices calculated for rural and urban temporal activity distribution

Metric	**Rural**	**Urban**
Sample size (N)	47	102
Mean time	10:31 AM	23:11 PM
r/rho (Mean Resultant Length)	0.193	0.406
Kappa	0.39	0.89
Circular Standard Deviation (h)	6.93 h	5.13
Kuiper Test (V)	1.43 **(p>0.15)**	3.74 **(p<0.01)**

With N=47, we fail to establish whether the rural Golden Jackals have a structured time activity pattern (V=1.43, p>0.15). The mean resultant length (0.193), kappa (0.39) and Circ SD (6.93h) points to a very dispersed activity pattern with no consistent peak. This renders the rural mean time of 10.31AM uninterpretable.

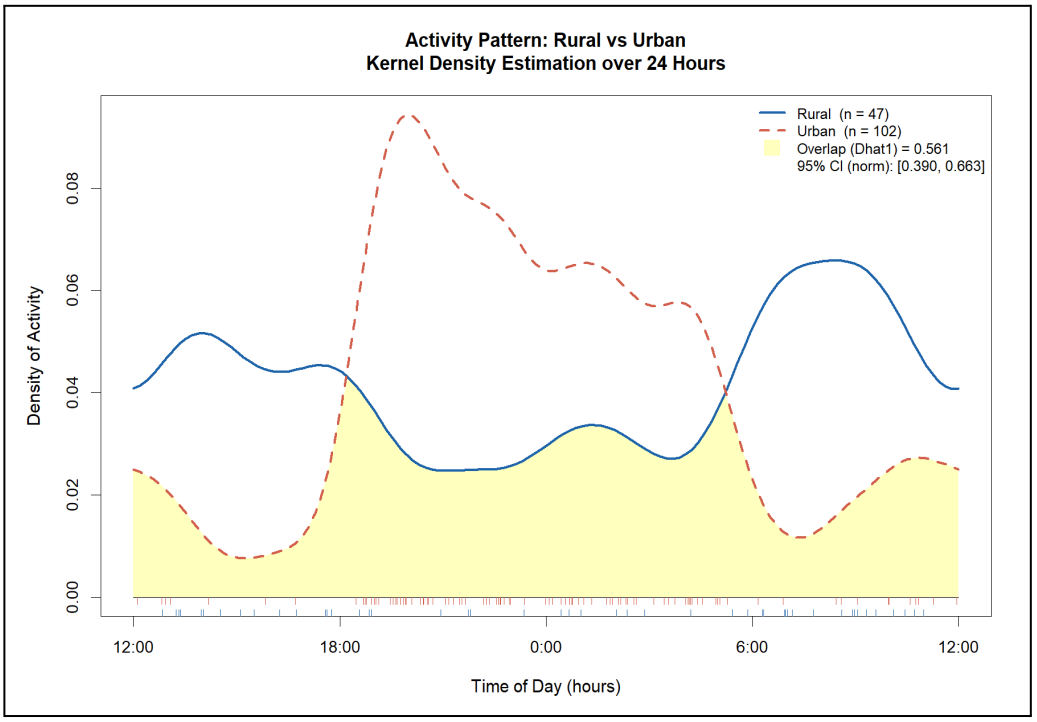
Whereas, with N=102, the urban activity times points towards a non-uniform and clearly structured activity pattern (V=3.74, p<0.01). The mean resultant length (0.406), kappa (0.89) and Circ SD (5.13h) points towards a significant nocturnal peak around 23:11 PM.





The Watson's Two sample test of Homogeneity (U^2= 0.6497) with p-value <0.001 indicates that rural and urban time activity patterns come from different temporal distributions.

The coefficient of overlap (Dhat1=0.561, 95% CI [0.39-0.66]) obtained during Kernel Density Estimation shows that there is moderate overlap of 56.1% between urban and rural time activity. pattern.



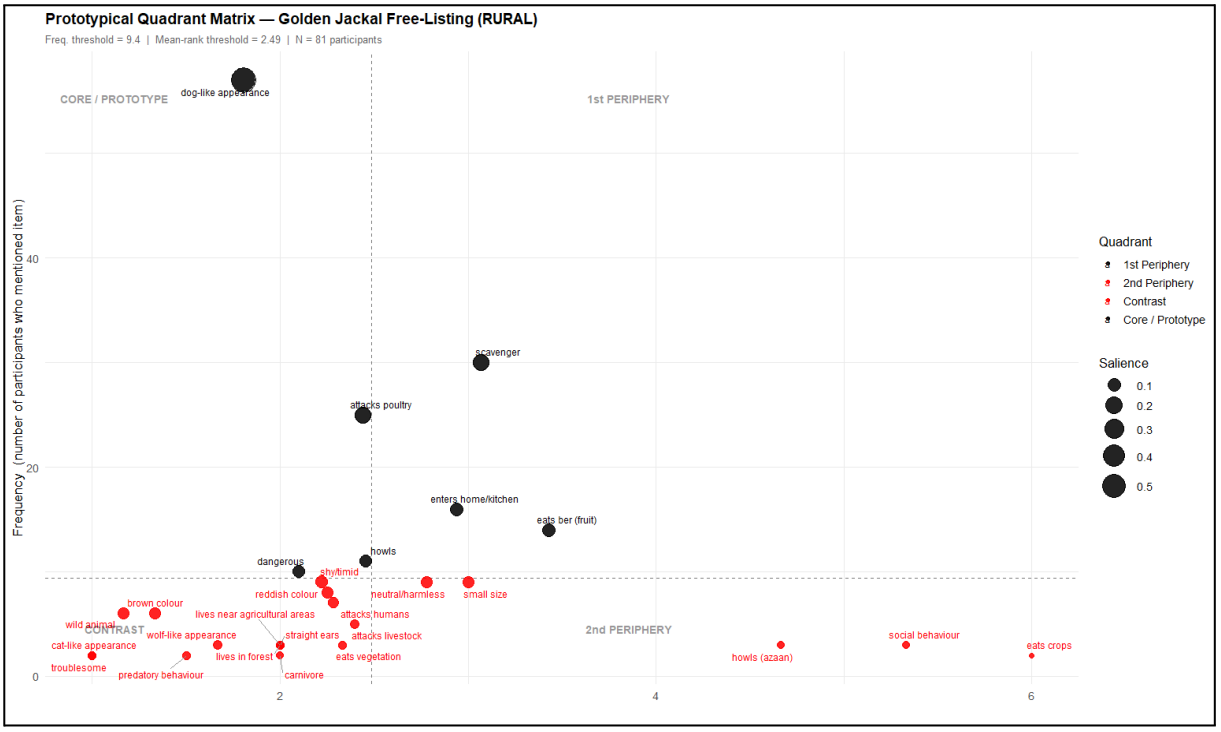
The below table exhibits the frequency of different time blocks used by Golden Jackal in rural and urban environments.

Table 7: Frequency of time blocks in rural and urban environments

	Dawn	**Day**	**Dusk**	**Night**	**Total**
Rural	1	28	2	16	**47**
Urban	10	18	1	73	**102**
Total	11	46	3	89	**149**

The Fisher's Exact Test (Monte Carlo, B=100,000) confirms statistically significant association between habitat type (rural and urban) and time block use with $p < 0.00001$ and Cramer's V=0.45. Rural jackals were found to be diurnal (59.6% day) while urban jackals were more nocturnal (71.6%).

6.3 Socio-ecological Survey



The rural quadrant matrix tells that rural social representation is centered around 'dog-like appearance' with high frequency and low mean rank. It hints that the rural population associates Golden Jackal's physical resemblance to domestic dogs and that is how the primary identification is built around jackals.

Terms like ‘scavenger’, ‘enters home/kitchen’ and ‘eats fruit’ are commonly shared but falls in less central knowledge. The items in contrast zone such as ‘brown color’, ‘wild animal’, ‘predatory behaviour’ have less frequency but low mean rank indicating personal experiences and minority viewpoints. Whereas items like ‘social behaviour’ and ‘howls during azaan’ which fall in the second periphery are less frequent and show weaker association.

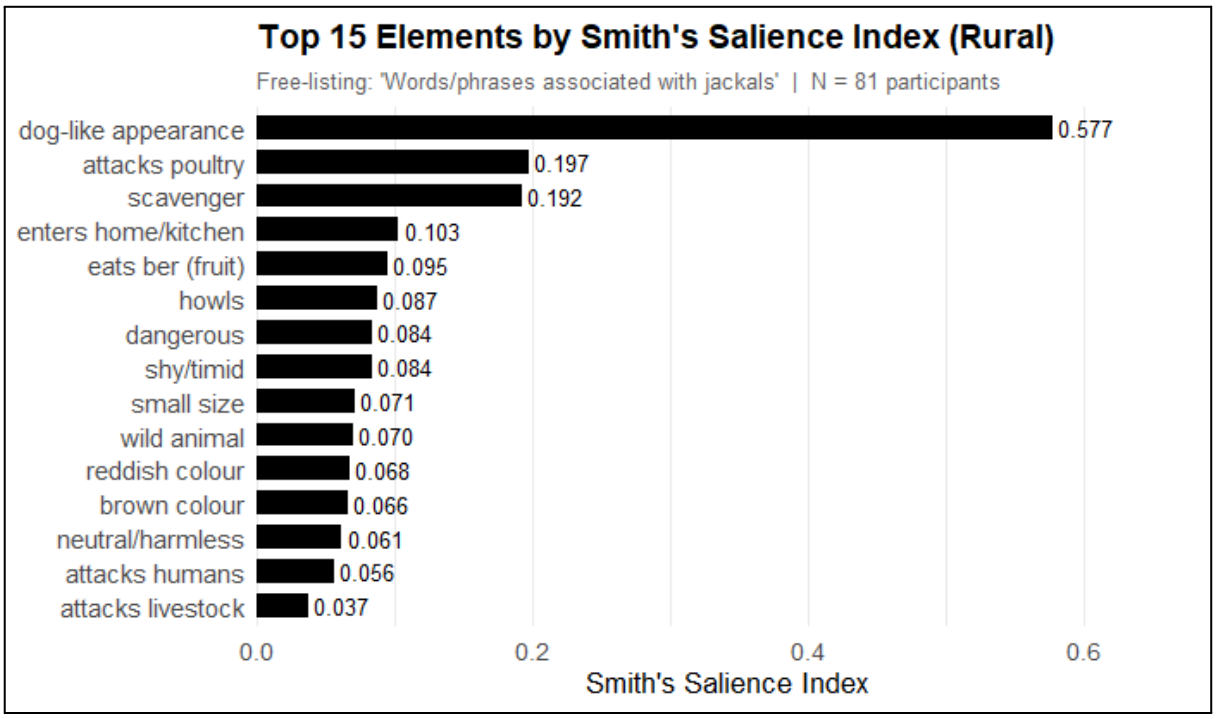
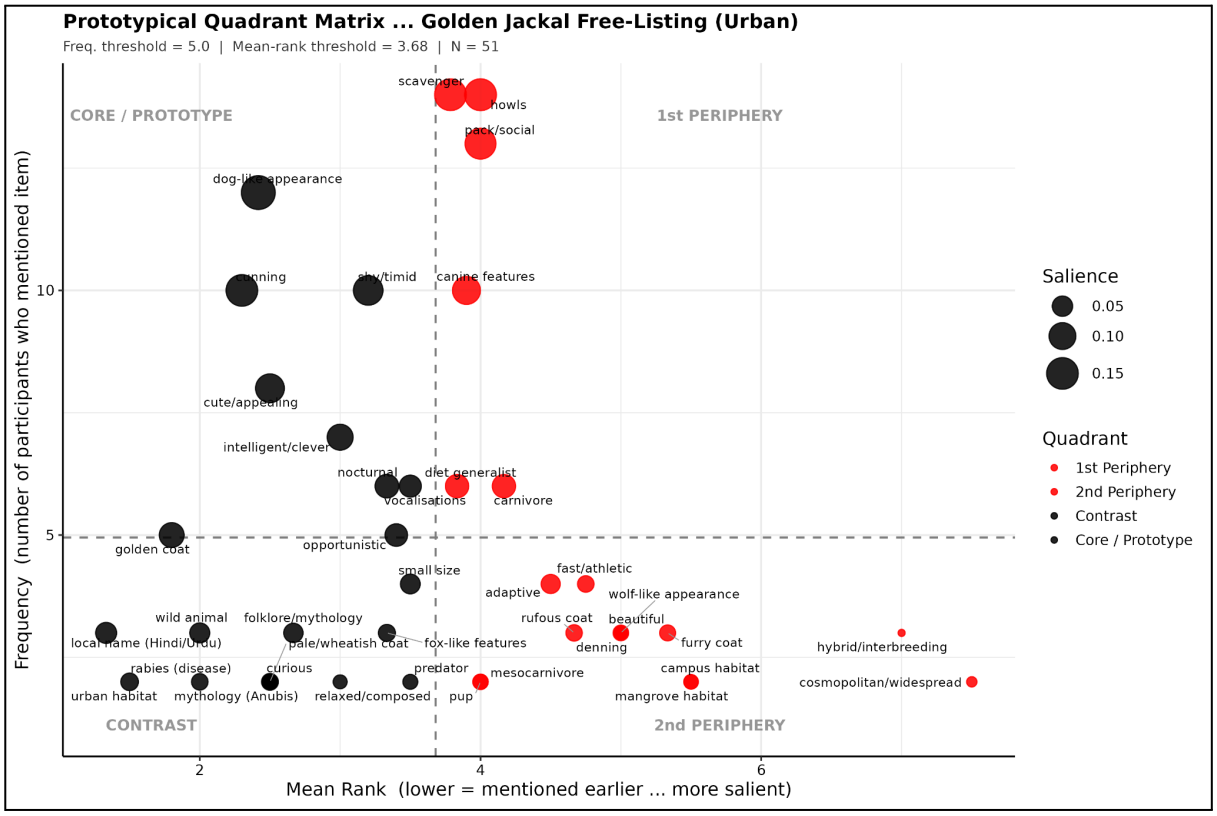
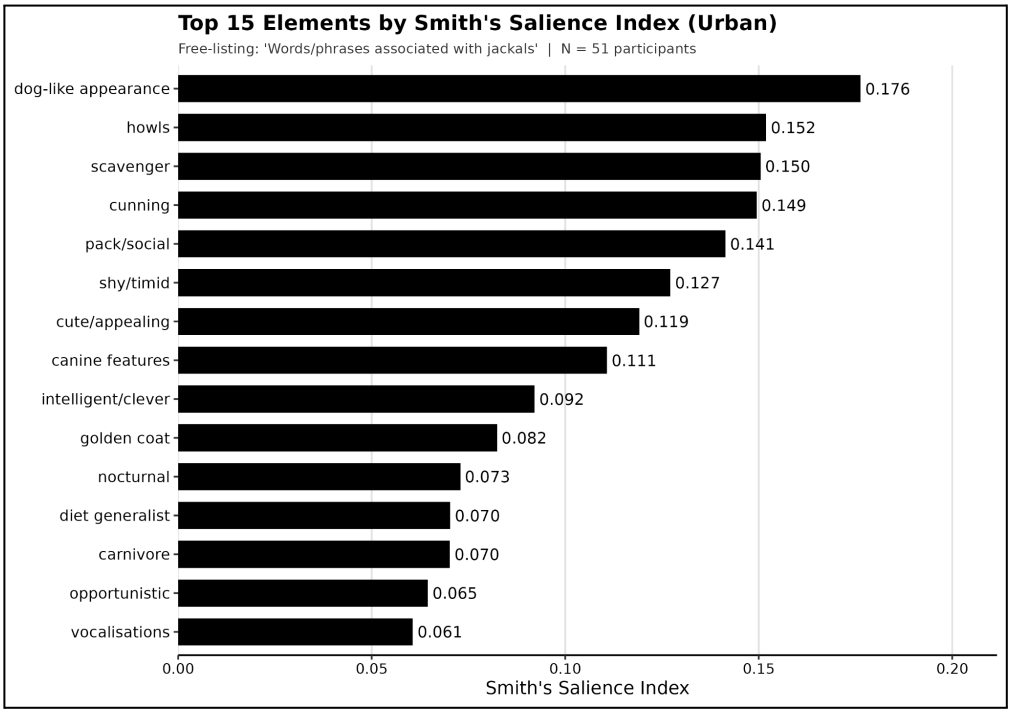
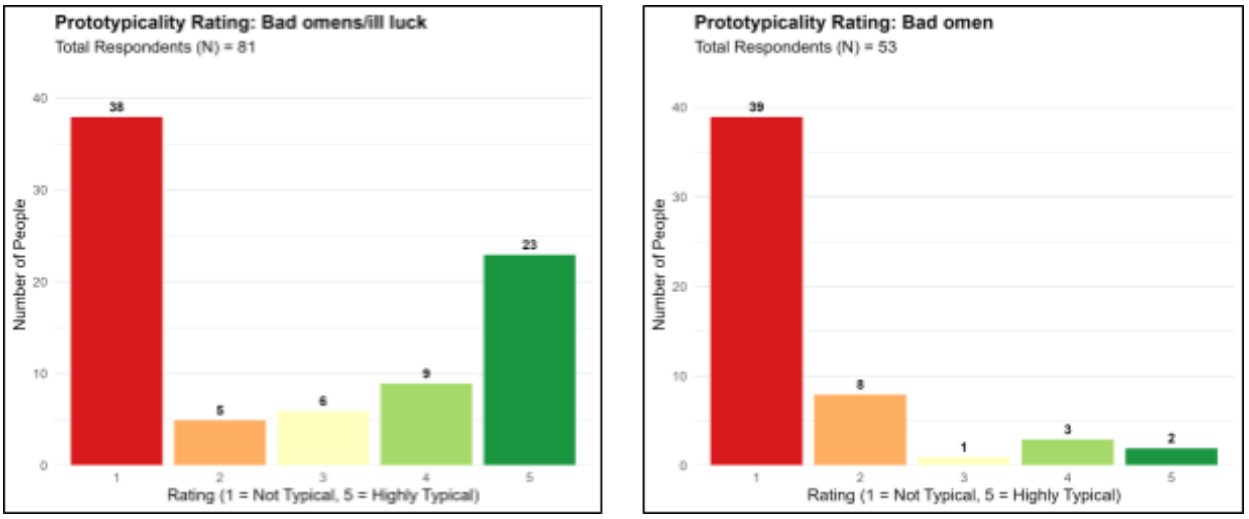


Figure 15: Smith's Salience Index - Rural

For urban social representation, the ideas in the core zone are still driven by physical characteristics similar to dogs and behavioural traits such as shy, timid, cute and cunning. The items in first periphery like scavenger, howls and generalist diet show high frequency but also high mean rank indicating that a large section of people see them as scavengers and associate similar canid features but don’t consider these items as the ones with most importance. The urban audience places terms like local names, mythological inferences, diseases and jackals. Whereas the second periphery have words such as athletic, cosmopolitan and ideas of interbreeding.


Prototypical Quadrant Matrix ... Golden Jackal Free-Listing (Urban)
Freq. threshold = 5.0 | Mean-rank threshold = 3.68 | N = 51
CORE / PROTOTYPE
1st PERIPHERY
CONTRAST
2nd PERIPHERY
scavenger
howls
pack/social
dog-like appearance
cunning
shy/timid
canine features
cute/appealing
intelligent/clever
nocturnal
diet generalist
vocalisations
carnivore
golden coat
opportunistic
small size
fast/athletic
adaptive
wolf-like appearance
wild animal
folklore/mythology
rufous coat
beautiful
local name (Hindi/Urdu)
pale/wheatish coat
fox-like features
denning
furry coat
hybrid/interbreeding
rabies (disease)
curious
predator
mesocarnivore
campus habitat
cosmopolitan/widespread
urban habitat
mythology (Anubis)
relaxed/composed
pup
mangrove habitat
Frequency (number of participants who mentioned item)
Mean Rank (lower = mentioned earlier ... more salient)
Salience
0.05
0.10
0.15
Quadrant
1st Periphery
2nd Periphery
Contrast
Core / Prototype


Top 15 Elements by Smith's Salience Index (Urban)
Free-listing: 'Words/phrases associated with jackals' | N = 51 participants
dog-like appearance 0.176
howls 0.152
scavenger 0.150
cunning 0.149
pack/social 0.141
shy/timid 0.127
cute/appealing 0.119
canine features 0.111
intelligent/clever 0.092
golden coat 0.082
nocturnal 0.073
diet generalist 0.070
carnivore 0.070
opportunistic 0.065
vocalisations 0.061
Smith's Salience Index



The urban population strongly rejected the notion of associating golden jackals to bad omen or ill luck whereas the rural population was divided on the extremes with people either strongly agreeing to the idea of jackals and bad omen or rejected straight forwardly.

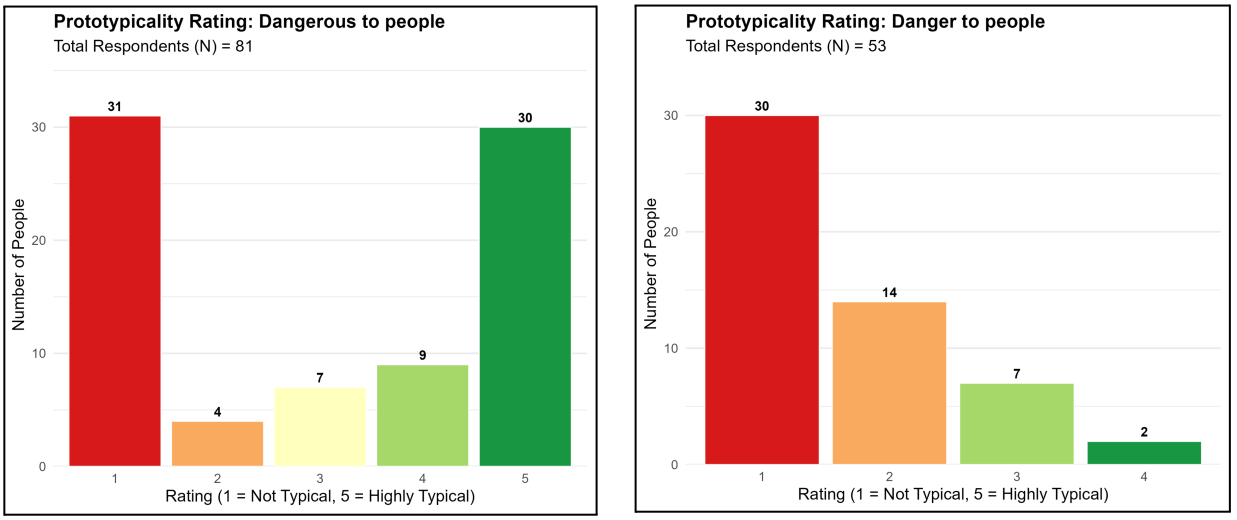
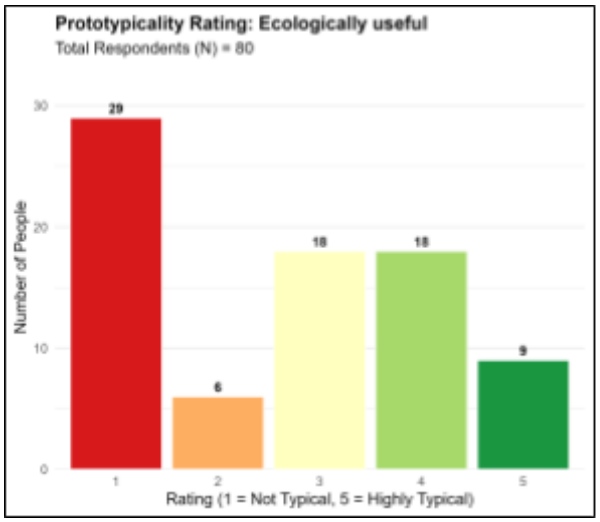
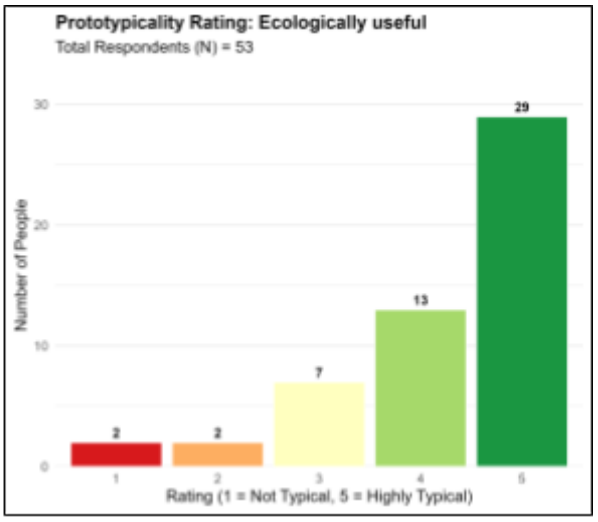


Figure 19: Prototypicality Rating for Rural and Urban (left to right) - Dangerous to people

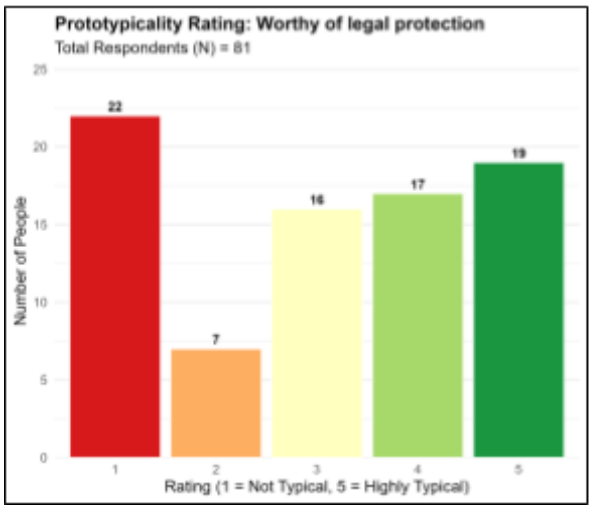
The rural population was again divided into two halves when asked whether Golden Jackals were dangerous to people whereas urban population rejected the idea completely.

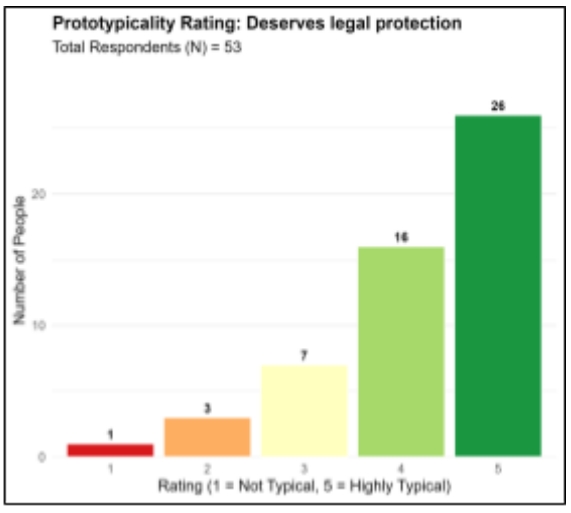


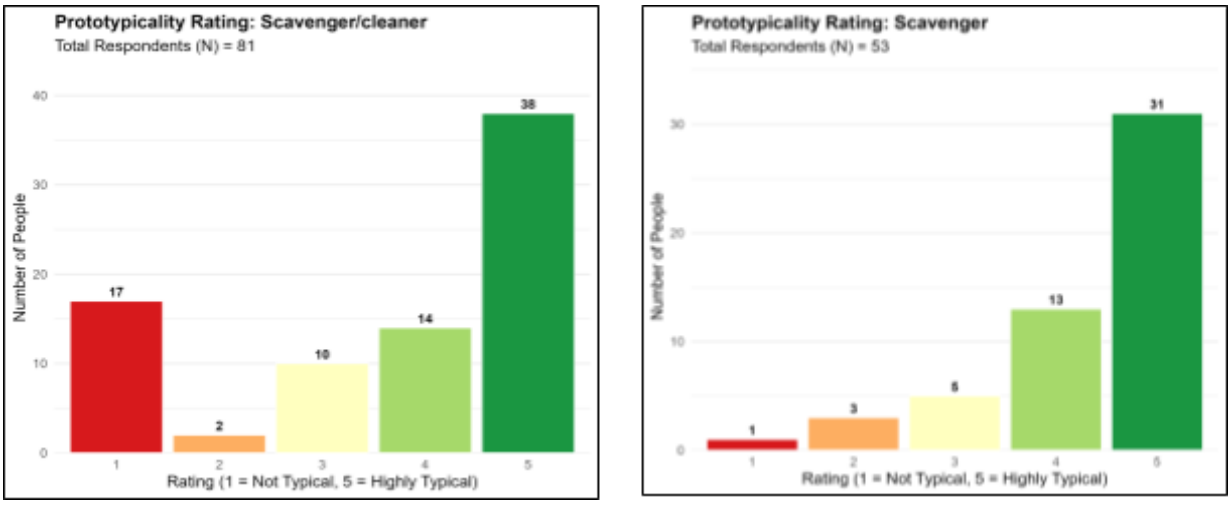


When asked about the Golden jackals' ecological usefulness, the major section of rural population showed disagreement whereas a more informed urban population agreed with the fact that jackals are useful and ecologically important.

When questioned about Golden Jackal getting legal protection, the responses were varied among rural respondents with a larger section of the population having no problem with it. But it's worth noting that some responses were also on the opposite end of the spectrum. On the other hand, the urban respondents were unanimously in support of golden jackals getting legal protection.

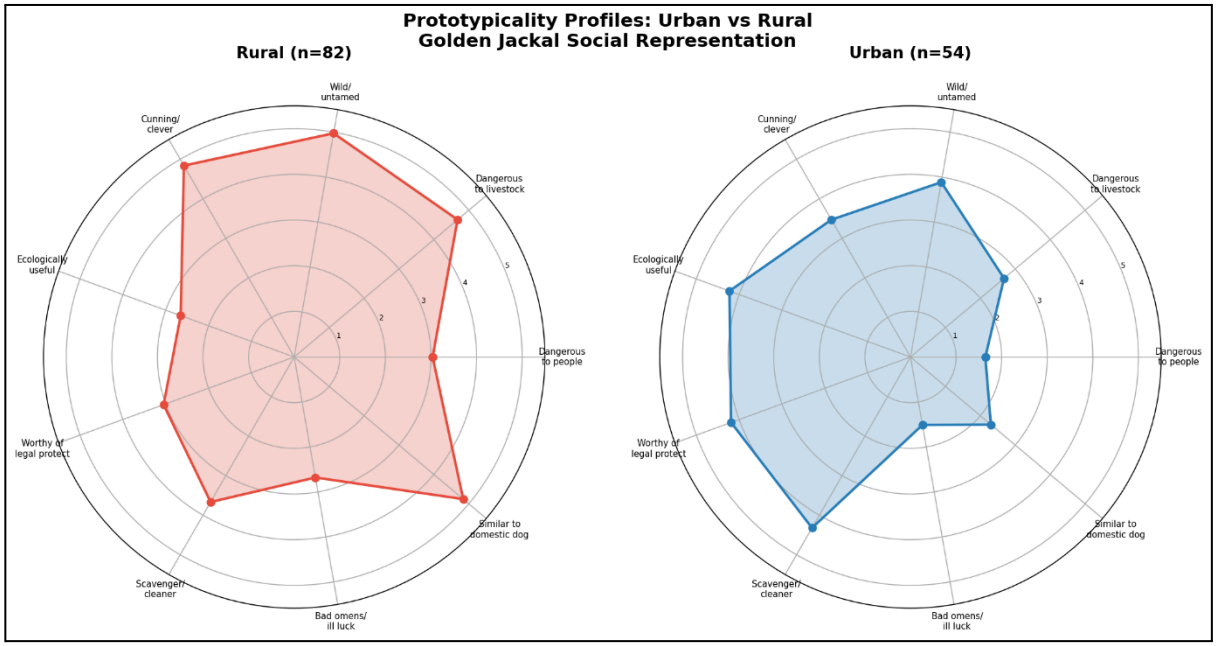






The rural and urban population did share the idea of Golden Jackals' role as a scavenger and cleaner of the environment.

Figure 23: Prototypicality Profiles - Rural vs Urban



For the semantic profile, respondents were presented with a bipolar scale. Each position on the continuum allows the respondent to express the intensity of their feeling toward the target.

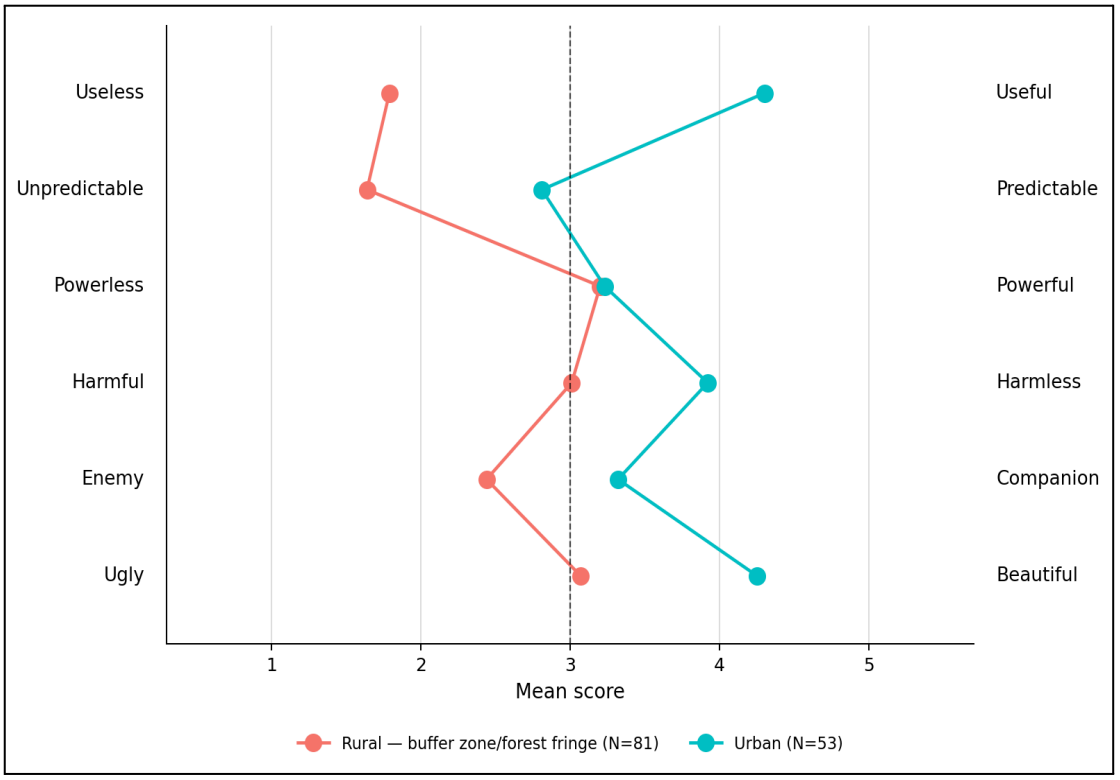
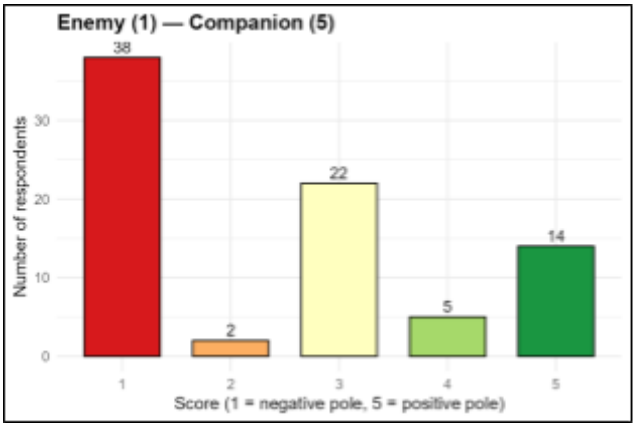
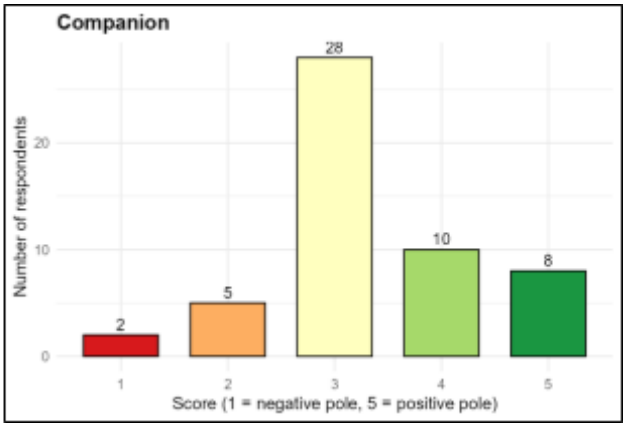
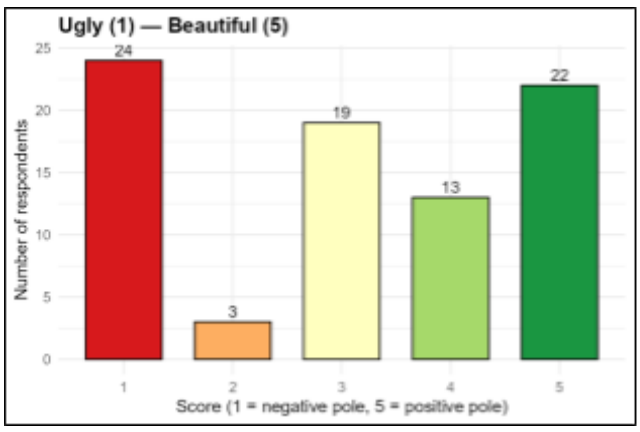
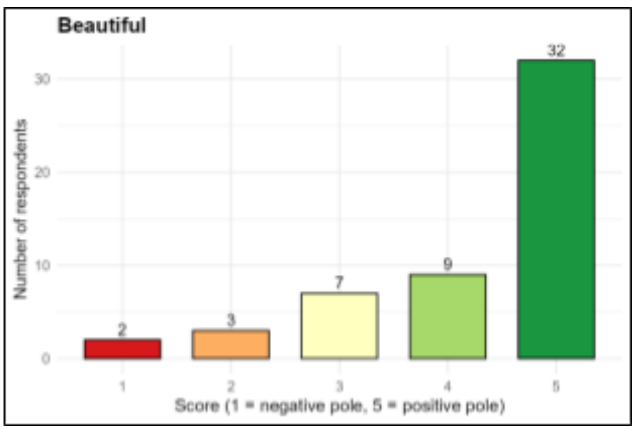


Figure 24: Semantic Profile - Rural vs Urban



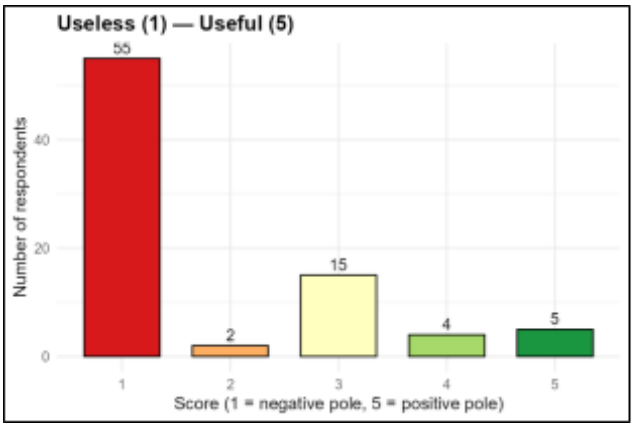


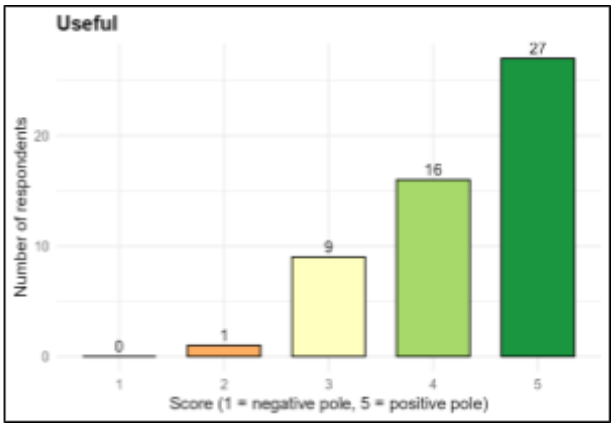


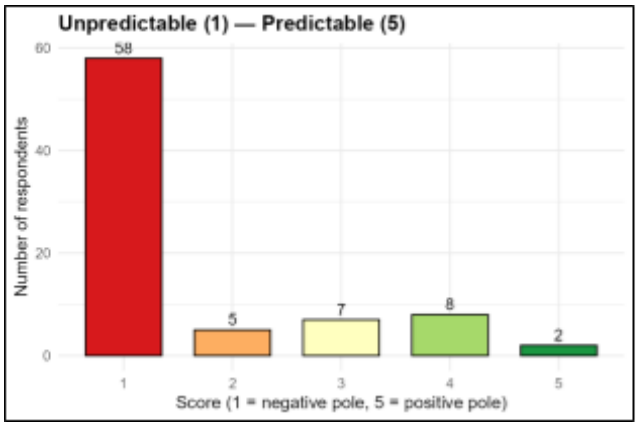


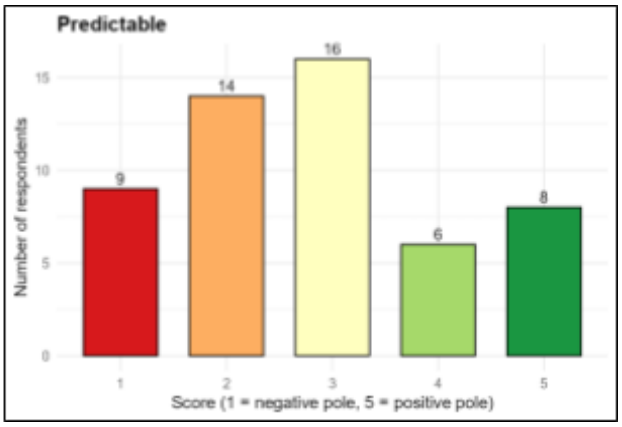
Where rural respondents found Golden Jackals to be enemies of humans, the urban population showed a neutral feeling.

On the question of Golden Jackals being visually appealing, the views among the rural population were spread across the spectrum whereas the urban population unanimously found them beautiful.









When asked about Golden jackals being predictable as a species, the rural population shared a common view of jackals being unpredictable whereas the urban population had mixed views.

The rural population shared a very strong view of considering the Golden jackal being a useless species to which the urban population's response was contrary as they believed jackals to be a very useful species.

7. Discussion

7.1 Bioacoustics

Out of the 75 measured parameters, 12 were selected to compare acoustic properties of Golden Jackal vocalisation events in rural and urban habitat type. The parameters were chosen to cover all the important acoustic domains. MFCCs 1,3 and 8 covered the spectral envelope texture. Spectral centroid, spectral skewness, spectral kurtosis covered the spectral shape and energy distribution. F4 mean for vocal tract filtering. f0 standard deviation, jitter, shimmer and harmonics to noise ratio to cover source level phonatory quality and duration took into account the temporal structure of golden jackal vocalisation.

Rural jackals produced vocalisation events much longer (40%) than urban jackals. It could be due to low to mid frequency anthropogenic noise such as traffic, dog barks and other activities as it hinders the acoustic content of longer vocalisations (Wiley 1982). It's also noteworthy that heightened vigilance which is also an artifact of the urban environment might be acting a role in production of shorter vocalisation. The calls might be longer in rural environments as it helps in long distance territorial advertisement and group coordination (Slabbekoorn & den Boer-Visser, 2006). The HNR mean quantifies the degree to which a signal is composed of periodic harmonic energy relative to aperiodic noise. High HNR values mean that sound is much cleaner, more tonal and harmonically structured while calls which are noisier and more rough have low HNR values. The prediction was that rural calls would be cleaner and urban calls should be rougher but it might be due to the fact that tonal and harmonically superior vocalisations propagate more effectively in noisy environments as their energy is more concentrated in predictable spectral lines. So, it is possible that urban jackals are producing cleaner calls to tackle urban noise masking. A parallel phenomenon has been described in urban great tits (Parus major), which produce songs with longer, more tonal elements in cities compared to forest-dwelling conspecifics (Halfwerk & Slabbekoorn, 2009).

Spectral centroid is described as the centre of gravity of the spectrum. It explains tonal character and high spectral centroid values indicate that higher frequencies have energy concentration (brighter sound) while low spectral centroid values indicate energy concentration in lower frequencies. Spectral centroid for rural jackals is much higher than urban. The vocal frequency shift hypothesis says that animals in disturbed environments tend to shift their vocalisations to higher frequencies to use the relatively quieter high frequency acoustic niche. This sounds contradictory as if rural jackals are in disturbed environment but if we look at the complex harmonic vocalisations of Golden jackals it makes sense. In an undisturbed rural environment, jackals use high frequency space to transfer rich information whereas in noisier urban environments, high frequency components get shadowed by broadband noise making them unreliable.

Principal Component analysis

The PCA was performed using 12 acoustic variables. PC1 explained 37.4% and PC2 explained 16.5% of the variance respectively. So together they explained 53.9% of the variance. The positive loadings of PC1 included mfcc1_mean (0.436), spec_skewness_mean (0.396), spec_kurtosis_mean (0.325), mfcc8_mean (0.248), hnr_mean (0.232) and jitter_local (0.185). These all variables were higher in urban jackal vocalisations. The negative loadings included spec_cog_mean (-0.392), mfcc3_mean (-0.341), f4_mean (-0.251) and duration (-0.210)- the variables higher for rural jackals vocalisation . Therefore we can say that PC1 separates spectrally brighter, acoustically elaborate and long duration rural vocalisations from spectrally darker, tonally denser and shorter urban vocalisations.

PC2 has negative loadings from jitter_local (-0.472), shimmer_local (-0.491), f0_sd (-0.453) and positive loadings from spec_kurtosis_mean (0.379) and spec_skewness_mean (0.282). Positive spectral values and low values for variables responsible for phonatory qualities indicate within group variation and this might be due to intra-group variation showcasing call type heterogeneity.

7.2 Camera Trap

Circular statistical framework was used for temporal data as it takes into account the cyclical nature of the 24-hour clock (Lund et al.,2017). The two research questions based on the diel activity pattern of Golden Jackals which we tried to explore were to understand if habitat type leads to shift in diel activity pattern (Proudman et al.,2025). The first question was to understand if each group/population (rural and urban) have a structured diel activity pattern or it is uniformly distributed around the 24-hour clock. To test it, we ran the Kuiper test, which is a better alternative to the Rayleigh test as it takes into account multimodal clustering. The rural jackals ($V=1.433$, $p>0.15$) showed no significant departure from uniformity but urban jackals ($V=3.738$, $p<0.01$) showed significant results aiming at non uniform activity. This suggests that rural jackals at a population level might be having a flexible opportunistic activity and don't have a statistically structured diel rhythm whereas the urban jackals were found to have a highly structured activity pattern which might be an attempt to avoid peak human activity hours (Tigas et al.,2002). The second research question was to understand if rural and urban jackal populations differ in their activity time. To test it, we ran Watson's two sample test which is a non-parametric test for circular data. The results were highly significant ($U^2 =0.652$, $p<0.001$) which suggests towards habitat mediated shifts in diel activity. The results align with a study on coyotes from the US where the authors found that in areas of high human disturbance the coyotes selected more nocturnal hours (Gallo et al.,2022; Mayer et al., 2023). The Kernel Density Estimation provides a continuous representation of two activity distributions. The overlap coefficient Dhat1=0.561 suggests that rural and urban jackals share 56% of their temporal activity. The rural jackals show peaks in late morning and late afternoon or early evening hours which sits well with golden jackal's crepuscular to diurnal activity in rural habitat with open lands and agricultural areas. Whereas urban jackals' activity peaks at night around 23:00 hr and again rises around pre-dawn.

The time block analysis reveals a highly significant association between habitat type and time block use. Rural jackals were found to be diurnal (59.6% day) while urban jackals were more nocturnal

(71.6%). Gaynor et al.,(2018) in their meta-analysis of diel activity pattern of 72 mammal species found out that animals tend to increase their nocturnality by a factor of 1.36 in response to human disturbance.

7.3 Socio-ecological Survey

The SRT framework was used to understand the underlying social representational structure of Golden Jackals. The most important finding from the prototypical quadrant matrix was that "dog-like appearance" was the most salient free listed item with Smith's Salience Index of 0.577 for rural subjects and 0.176 for urban. It occupied the Core quadrant in both the rural and urban quadrant matrix. The results align with the theoretical framework of Social Representation theory which states that humans have a tendency to classify novel objects by reference to familiar categories. Dog-like appearance in rural and canid features in urban matrix was used by respondents to anchor jackals to something which they interact with commonly.

The very high salience score of 0.577 for rural population highlights frequent contact and proximity with the animal compared to urban population which sees the animal more as a 'scavenger' and associates it with local names and folklores- a knowledge based on literature, media and mythology. The urban subjects mostly ecology/wildlife and conservation professionals structured their representation around ecological and behavioural traits such as howling (0.152), scavenging behaviour (0.150), social animals (0.141) which is understandable as they are supposed to be informed and have knowledge about golden jackal as a species. The frequent use of items like 'cunning', 'cute', 'shy' portrays that urban audiences who lack direct contact or conflict with carnivore animals tend to develop anthropomorphic representation. This fits perfectly into urban-nature disconnect.

Rural respondents structured their representations in contrast with the urban respondents where their salient items were 'attacks poultry' (0.197), 'enters home/kitchen' (0.103), 'scavenger' (0.192) which shows their interactions are more physical and direct. This also leads to them developing negative

views about the species because their interactions lead to monetary loss or direct threat. Where urban respondents think Golden jackal as a 'diet generalist' (0.07), the rural respondents have more detailed ecological observations with 'eat fruits (ber)' (0.095) being the fifth most salient word.

The results for prototypicality ratings gathered fundamentally different attitudes towards Golden Jackals between rural and urban respondents. 79.2% urban respondents found jackals to be ecologically useful which points to their formal education and exposure to ecologically correct information. The rural respondents on the other hand only scored them 43.8% when asked about ecologically usefulness. Urban people rated golden jackal as non-dangerous to people while rural respondents showed bimodality in their answers where 37% rated them as dangerous and 38.3% as non-dangerous. This reflects rural respondents having varied interactions with golden jackals. On the question of jackals associated with bad omen and ill luck, the urban audience as expected rejected the notion with 73.6% rating as not typical. On the other hand, rural respondents showed bimodal distribution where 46.9% rated as not associated with bad omen while 28.4% believed in the idea of golden jackals bringing ill luck. This result holds relevance as this shows polyphasia of social representations where members of the same community hold contradictory representations (ref). The same pattern was observed when interrogated about golden jackals being worthy of legal protection. The urban respondents were in favour with 79.2% ratings whereas in the case of rural respondents 27.2% opposed, 23.5% strongly supported and 19.8% showed neutrality. The semantic differential profiles were mostly positive for urban subjects with 60.4% of them finding them beautiful whereas the rural respondents had mixed visual appeal. Rural respondents saw them as useless (67.9%) creatures who cause nuisance but it was opposite for urban respondents who rated them as useful (81.1%). Even though the rural respondents interacted with the jackals in their everyday life 71.6% of them found them unpredictable.

8. Conclusion

The study on Golden Jackal was aimed to understand how change in habitat influences the jackals acoustic ecology and diel activity pattern. Additionally, an attempt was made to gauge the social representation of Golden jackals from rural audience who interact with the species in their everyday lives and another group constituted of people who belonged from wildlife, ecology and conservation. Rural jackals produced vocalisation events much longer (40%) than urban jackals. Urban jackals produced cleaner calls to tackle urban noise masking. Rural jackals produced spectrally brighter, acoustically elaborate and long duration vocalisations whereas urban jackals produced spectrally darker, tonally denser and shorter urban vocalisations. Rural jackals were found to be diurnal (59.6% day) while urban jackals were more nocturnal (71.6%). The most important finding from the prototypical quadrant matrix was that “dog-like appearance” was the most salient free listed item. Social representation between rural and urban showcased different attitudes and understanding about the species.

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APPENDIX I

Variable	Definition / Meaning	Theoretical Basis	Significance in Bioacoustic Study
TEMPORAL FEATURE			
duration	Total length of the call in seconds, measured from onset to offset of vocalisation.	Call duration is a fundamental temporal descriptor in bioacoustics (Marler & Slabbekoorn, 2004). It reflects the overall energetic investment and communicative intent of the vocaliser.	Differentiates call types (e.g., short alarm barks vs. long howls) and can reveal context-dependency. In golden jackals, longer calls are associated with territorial and social bonding functions.
FUNDAMENTAL FREQUENCY (F0)			
f0_mean	Mean fundamental frequency (F0) of the call, representing the average rate of vocal fold vibration across the entire call duration (measured in Hz).	F0 is the primary determinant of perceived pitch (Titze, 1994). In non-human animals, F0 encodes body size, arousal, and individuality (Taylor & Reby, 2010).	Serves as the key pitch descriptor for jackal vocalisations. Higher mean F0 may indicate smaller body size or elevated arousal; lower F0 indicates dominant, settled individuals.
f0_min	Minimum F0 value recorded within the call, capturing the lowest pitch point reached during vocalisation.	The lower bound of F0 reflects the maximum relaxation of vocal folds (Fitch & Hauser, 2002). It is informative about the lower limit of an individual's vocal tract capacity.	Useful for detecting call modulation depth and emotional valence. Very low minima relative to mean may indicate non-linear phenomena (e.g., frequency jumps) associated with high arousal.
f0_max	Maximum F0 value recorded within the call, capturing the highest pitch point reached during vocalisation.	The upper bound of F0 reflects maximum vocal fold tension (Titze, 1994). It constrains the upper register available to the individual.	Reveals the pitch ceiling of the call. Large gaps between f0_min and f0_max signal high pitch dynamism, indicative of communicative complexity or emotional escalation in jackal calls.
f0_sd	Standard deviation of F0 across the call, quantifying pitch variability or modulation depth around the mean.	F0 variability encodes prosodic complexity and emotional expressiveness (Briefer, 2012). High SD indicates a highly modulated, dynamic call.	High F0 SD in jackal calls may signal contact calls or agonistic interactions requiring dynamic pitch modulation; low SD suggests stereotyped, fixed calls (e.g., alarm barks).
abrupt_f0_ts0025	Proportion of time steps (at 0.025 s resolution) where an abrupt, discontinuous jump in F0 occurs, indicating non-linear vocal phenomena.	Abrupt F0 discontinuities (frequency jumps, biphonation) are non-linear vocal phenomena (NLPs) arising from asymmetric vocal fold vibration (Fitch et al., 2002). They are honest signals of arousal.	NLPs at fine timescales (25 ms) capture rapid, transient pitch instabilities. Frequent abrupt jumps may indicate high stress or urgency in jackal vocal communication.
abrupt_f0_ts005	Proportion of time steps (at 0.05 s resolution) where abrupt F0 jumps occur — a coarser temporal threshold for detecting pitch discontinuities.	Same NLP framework as above (Fitch et al., 2002), but at a 50 ms window — better aligned with perceptual processing timescales in mammalian auditory systems.	Bridges fine- and coarse-grained instability detection. Comparing ts0025 and ts005 values reveals whether pitch discontinuities are momentary (fine) or sustained (coarse).
abrupt_f0_ts01	Proportion of time steps (at 0.1 s resolution) where abrupt F0 jumps occur — the coarsest of the three NLP temporal thresholds used here.	At 100 ms resolution, this captures NLPs that are perceptible to conspecific receivers (Fitch et al., 2002; Blumstein et al., 2004). Receiver-relevant timescale for signal evaluation.	High values at ts01 indicate sustained pitch instability perceptible to conspecifics, likely elevating attention and social response. Useful for predicting receiver behavioural reactions.
FORMANTS — F1			
f1_mean	Mean frequency of the first formant (F1) — the lowest resonance frequency of the vocal tract, shaped primarily by jaw opening and tongue height.	Formants are resonances of the supralaryngeal vocal tract (Fant, 1960). F1 inversely correlates with vocal tract length, making it a proxy for perceived body size (Fitch & Hauser, 2002).	F1 is critical for vowel-like distinctions in animal calls. Lower F1 in jackal calls may signal larger body size or dominance; higher F1 may be associated with submissive or contact vocalisations.

Variable	Definition / Meaning	Theoretical Basis	Significance in Bioacoustic Study
f1_min	Minimum value of the first formant frequency across the call, reflecting the lowest point of vocal tract constriction-driven resonance.	Within-call F1 minima capture extreme vocal tract configurations (Titze, 1994). They reveal the lower boundary of the F1 trajectory.	Tracks the most constricted vocal tract state during the call. Low F1 minima may correspond to specific call segments with enhanced body-size encoding, relevant for competitive signalling.
f1_max	Maximum value of the first formant frequency across the call duration.	F1 maxima reflect the most open vocal tract configuration (Fant, 1960). Together with F1_min, they define the dynamic range of F1 modulation.	Wide F1 range (max minus min) indicates dynamic articulation during the call. In jackals, this may distinguish howls (highly modulated F1) from barks (stable F1).
f1_sd	Standard deviation of F1 across the call, quantifying temporal variability of the first formant.	F1 variability reflects articulatory dynamics of the jaw and tongue (Stevens, 1998). High SD indicates active supralaryngeal modulation during vocalisation.	Captures the degree to which jackals actively reshape their vocal tract during a call. High F1 SD may indicate complex, multi-note calls; low SD suggests tonally stable, uniform calls.
FORMANTS — F2			
f2_mean	Mean frequency of the second formant (F2), shaped primarily by tongue advancement and overall vocal tract geometry.	F2 is the primary cue for place-of-articulation distinctions (Fant, 1960). In animal calls, F2 encodes subtle vocal tract shape differences beyond body size.	Provides information about the mid-resonance structure of jackal calls. Differences in F2_mean across call types or individuals may indicate population-level or individual-level vocal signatures.
f2_min	Minimum F2 frequency recorded across the call — the lowest mid-resonance point reached.	Lower F2 values reflect posterior tongue positioning or longer effective vocal tract length (Stevens, 1998).	Useful for identifying call segments with posterior articulation. Low F2 minima may mark specific call phases (e.g., onset or offset) that carry particular social information.
f2_max	Maximum F2 frequency recorded across the call.	F2 maxima correspond to anterior tongue positioning or shortened effective vocal tract (Fant, 1960).	Helps delineate the upper resonance range of the call. Together with F2_min, reveals the formant trajectory span — informative for classifying call modulation complexity.
f2_sd	Standard deviation of F2 across the call, quantifying temporal variability of the second formant.	F2 dynamics reflect supralaryngeal articulatory activity (Stevens, 1998). High SD implies active, changing vocal tract geometry during the call.	High F2 SD may signal multi-segmented or tonally complex calls. Cross-individual variation in F2 SD may encode behavioural context differences (territorial vs. contact calls).
FORMANTS — F3			
f3_mean	Mean frequency of the third formant (F3), shaped by complex interactions of tongue body, tip, and pharyngeal wall.	F3 is a secondary resonance carrying fine-grained vocal tract shape information (Fant, 1960). In animal bioacoustics, higher formants contribute to timbre and individuality.	Contributes to the spectral 'texture' of jackal calls. F3 differences across individuals may support individual recognition, important in territorial and pack-level communication.
f3_min	Minimum F3 frequency across the call.	Reflects the most elongated or complex vocal tract configuration encountered during the call (Stevens, 1998).	Low F3 minima can correspond to low-frequency tonal segments within a call. Tracking these across contexts can reveal structured temporal patterning in jackal vocal sequences.
f3_max	Maximum F3 frequency across the call.	Reflects the shortest or most simplified vocal tract configuration (Fant, 1960).	High F3 maxima may be associated with high-pitched call segments. Useful for differentiating call categories in repertoire analyses using formant trajectories.

Variable	Definition / Meaning	Theoretical Basis	Significance in Bioacoustic Study
f3_sd	Standard deviation of F3 across the call.	F3 variability encodes higher-order vocal tract articulation dynamics (Stevens, 1998). It is particularly sensitive to individual-level differences in vocal technique.	High F3 SD contributes to the complexity of the spectral envelope. May differentiate experienced adult callers (stable F3) from juveniles (highly variable F3) in jackals.
FORMANTS — F4			
f4_mean	Mean frequency of the fourth formant (F4), primarily determined by glottal configuration and posterior pharyngeal shape.	F4 is a higher resonance that contributes to voice quality and individual distinctiveness (Titze, 1994). It is less affected by articulation and more by structural anatomy.	F4 is relatively stable within individuals, making it a strong candidate for individual identity encoding. Consistent group-level F4 differences may signal population distinctiveness.
f4_min	Minimum F4 frequency across the call.	Lower F4 values reflect anatomical configurations of the posterior vocal tract (Fant, 1960).	Captures the lower boundary of higher-order resonances. Together with F4_max, defines the range of higher formant dynamics, informative for timbre classification.
f4_max	Maximum F4 frequency across the call.	Reflects the upper limit of the fourth resonance mode (Titze, 1994).	Useful for detecting spectral broadening or narrowing of higher formants. Broadening (high F4_max) may indicate elevated arousal or a non-linear vocal production mode.
f4_sd	Standard deviation of F4 across the call.	F4 variability is driven by subtle changes in posterior vocal tract geometry (Stevens, 1998).	Low F4 SD indicates a structurally stable upper resonance — typical of habitual callers with fixed vocal production motor patterns. High SD may signal contextual or developmental variation.
FORMANTS — F5			
f5_mean	Mean frequency of the fifth formant (F5), the highest routinely trackable resonance, primarily shaped by the nasal cavity and epilaryngeal tube.	F5 encodes the finest resonance structure of the vocal tract (Fant, 1960). It is rarely used in isolation but contributes to multi-formant speaker-recognition models.	Provides the highest-frequency resonance descriptor for jackal calls. Used in multi-formant discriminant analyses to improve individual and population classification accuracy.
f5_min	Minimum F5 frequency across the call.	Minimum F5 values reflect the lower bound of the highest resonance mode (Stevens, 1998).	Useful as a diagnostic lower boundary for spectral complexity at high frequencies. Complements lower formant minima in full formant trajectory analyses.
f5_max	Maximum F5 frequency across the call.	Captures the ceiling of the fifth vocal tract resonance (Fant, 1960).	Provides the upper spectral boundary across five formant channels. Useful for full spectral envelope reconstruction in detailed vocal repertoire studies.
f5_sd	Standard deviation of F5 across the call.	F5 dynamics encode fine-grained nasal and epilaryngeal resonance modulation (Titze, 1994).	High F5 SD may indicate nasal coupling variability during calls. Together with lower formant SDs, contributes to a comprehensive picture of articulatory complexity in jackal vocalisations.
INTENSITY			
intensity_mean	Mean sound intensity (amplitude) across the call, measured in decibels (dB SPL), reflecting average vocal effort.	Intensity encodes vocal effort and arousal level (Morton, 1977). It is the amplitude-domain correlate of communicative urgency in the Morton Motivation-Structural Rules framework.	Higher intensity calls reflect greater effort and urgency — relevant for alarm, territorial, and long-distance contact calls in golden jackals. Enables energy expenditure estimation.

Variable	Definition / Meaning	Theoretical Basis	Significance in Bioacoustic Study
intensity_min	Minimum intensity recorded within the call, indicating the quietest segment of the vocalisation.	Intensity minima occur at call boundaries or during within-call pauses (Marler & Slabbekoorn, 2004). They define the baseline energy envelope.	Captures soft call components that may carry close-range social information. Large differences between intensity_min and intensity_mean indicate amplitude-modulated, dynamically complex calls.
intensity_max	Maximum intensity recorded within the call, reflecting the loudest call segment and peak vocal output.	Peak intensity reflects maximum glottal airflow and subglottal pressure (Titze, 1994), indicative of high arousal or long-distance signalling intent.	Relevant for predicting transmission range of jackal calls. High intensity_max values are expected for territorial howls intended to reach conspecifics across landscape-scale distances.
intensity_sd	Standard deviation of intensity across the call, quantifying amplitude modulation depth.	Amplitude modulation (AM) is a primary encoding mechanism for emotional state in mammalian communication (Briefer, 2012).	High intensity SD indicates amplitude-modulated calls, which attract receiver attention more effectively. Useful for distinguishing rhythmically modulated contact calls from flat-amplitude alarm calls.
HARMONICS-TO-NOISE RATIO (HNR)			
hnr_mean	Mean Harmonics-to-Noise Ratio (HNR) across the call — the ratio of harmonic (periodic) energy to noise (aperiodic) energy, in dB.	HNR quantifies voice quality and periodicity of vocal fold vibration (de Krom, 1993). High HNR = tonal, periodic call; low HNR = noisy, breathy, or chaotic call.	Distinguishes tonal howls (high HNR) from rough, noisy barks or growls (low HNR) in jackal repertoires. HNR is sensitive to stress and arousal state, decreasing during intense calls.
hnr_min	Minimum HNR value within the call — the noisiest, least periodic segment.	HNR minima capture segments of maximum noise injection, often caused by non-linear phenomena or high subglottal pressure (Fitch et al., 2002).	Low HNR minima may mark call segments of peak arousal or call onset bursts. Tracking HNR minima across call types reveals where noise is deliberately or physiologically introduced.
hnr_max	Maximum HNR within the call — the most tonal, periodic segment.	HNR maxima correspond to the most regular vocal fold oscillation within the call (de Krom, 1993).	Reveals the peak tonal quality achievable within the call. Comparing hnr_max across call types or individuals can quantify vocal tract control and health of the vocaliser.
hnr_sd	Standard deviation of HNR across the call, quantifying variability in voice quality over time.	HNR variability reflects transitions between tonal and noisy vocal production modes (Briefer, 2012), encoding dynamic changes in arousal or effort.	High HNR SD characterises calls that transition between tonality and noise — typical of complex multi-phase calls like the jackal group rally howl. Low SD indicates uniform voice quality throughout.
JITTER (FUNDAMENTAL PERIOD PERTURBATION)			
jitter_local	Local jitter: mean absolute difference between consecutive fundamental period durations, expressed as a percentage of the mean period.	Jitter quantifies cycle-to-cycle irregularity in vocal fold vibration (Baken & Orlikoff, 2000). It reflects micro-instabilities in the laryngeal oscillation mechanism.	Elevated jitter indicates vocal instability, associated with high arousal, distress, or vocal pathology. In jackals, jitter can differentiate relaxed contact calls from stressed alarm vocalisations.
jitter_rap	Relative Average Perturbation (RAP) jitter: smoothed jitter measured over a 3-period window, reducing sensitivity to outlier periods.	RAP jitter uses a running average to reduce noise in jitter estimation (Titze, 1994; Baken & Orlikoff, 2000). It is more robust than local jitter for signals with measurement noise.	Provides a more reliable jitter estimate for field recordings with environmental noise. RAP jitter is preferable over local jitter when signal quality varies across samples.
jitter_ppq5	Period Perturbation Quotient (PPQ5): jitter averaged over a 5-period window, capturing slower, low-frequency	PPQ5 jitter targets longer-timescale laryngeal perturbations (Baken & Orlikoff, 2000). It reflects sustained	Complements RAP jitter by capturing slower oscillatory instabilities. Comparing PPQ5 and local jitter allows decomposition of rapid vs.

Variable	Definition / Meaning	Theoretical Basis	Significance in Bioacoustic Study
	perturbations in vocal fold timing.	rather than momentary vocal fold irregularity.	sustained vocal perturbation — useful in graded signal analysis.
SHIMMER (AMPLITUDE PERTURBATION)			
shimmer_local	Local shimmer: mean absolute amplitude difference between consecutive vocal periods, expressed as a percentage of mean amplitude.	Shimmer quantifies cycle-to-cycle amplitude variability in vocal fold vibration (Baken & Orlikoff, 2000), reflecting glottal closure irregularity.	High shimmer is associated with rough, harsh call quality and elevated arousal. In jackal call grading, shimmer distinguishes smooth tonal vocalisations from rough agonistic calls.
shimmer_apq3	Amplitude Perturbation Quotient over 3 periods (APQ3): smoothed shimmer over a 3-period window.	APQ3 uses a short window to detect rapid amplitude perturbations (Titze, 1994). It is analogous to RAP jitter but for amplitude.	Captures short-timescale amplitude instabilities. APQ3 is useful for detecting rapid modulations at the fine temporal structure of calls, contributing to roughness perception in conspecific receivers.
shimmer_apq5	Amplitude Perturbation Quotient over 5 periods (APQ5): medium-window amplitude perturbation estimate.	APQ5 smooths amplitude perturbations over a slightly longer window (Baken & Orlikoff, 2000), targeting medium-timescale glottal irregularity.	Provides an intermediate amplitude variability estimate. In multi-measure shimmer analysis, APQ5 helps separate fine from coarse amplitude modulation, enabling finer resolution in call classification.
shimmer_apq11	Amplitude Perturbation Quotient over 11 periods (APQ11): coarser amplitude perturbation estimate, less sensitive to rapid fluctuations.	APQ11 captures slow, sustained amplitude perturbations (Titze, 1994). It is most analogous to perceived vocal roughness over longer call segments.	High APQ11 indicates sustained, perceptible amplitude roughness across the call — likely to affect conspecific receiver perception and behavioural response to the call.
SPECTRAL MOMENTS & SHAPE			
spec_cog_mean	Mean spectral centre of gravity (spectral centroid) — the amplitude-weighted mean frequency of the spectrum, indicating where spectral energy is concentrated.	Spectral centroid is the first spectral moment (Forrest et al., 1988). It reflects the overall brightness or darkness of the sound, analogous to timbral brightness in psychoacoustics.	Discriminates high-frequency tonal calls (high centroid) from low-frequency growls (low centroid). Spectral centroid is one of the most powerful single-feature call type classifiers in bioacoustics.
spec_spread_mean	Mean spectral spread (second spectral moment) — the standard deviation of spectral energy around the centroid, reflecting bandwidth and spectral dispersion.	Spectral spread is the second central moment of the spectrum (Forrest et al., 1988). It quantifies how broadly energy is distributed across frequencies.	High spectral spread indicates broadband, noise-like calls; low spread indicates narrowband, tonal calls. Distinguishes explosive alarm barks from pure-tone contact calls in jackal repertoires.
spec_skewness_mean	Mean spectral skewness (third spectral moment) — asymmetry of the spectral distribution around the centroid, indicating whether energy is concentrated above or below it.	Spectral skewness captures the asymmetry of the spectral envelope (Forrest et al., 1988). Positive skewness indicates energy concentrated at lower frequencies with a high-frequency tail.	Informative about the spectral shape of calls beyond centroid and spread. Jackal calls with energy concentrated in low harmonics and a fading high-frequency tail will show positive skewness.
spec_kurtosis_mean	Mean spectral kurtosis (fourth spectral moment) — peakedness of the spectral distribution, indicating whether energy is concentrated in a narrow or broad frequency band.	Spectral kurtosis quantifies spectral peakedness (Forrest et al., 1988). High kurtosis = energy concentrated in narrow spectral peaks; low kurtosis = flat, broadband distribution.	Distinguishes calls with sharp harmonic peaks (high kurtosis, tonal calls) from noisy broadband calls (low kurtosis). Useful for separating howls from barks in jackal repertoire analyses.
spec_flatness_mean	Mean spectral flatness (Wiener entropy) — the ratio of geometric to arithmetic mean of the power spectrum, ranging from 0 (pure tone) to 1 (white noise).	Spectral flatness quantifies tonal vs. noise-like spectral character (Johnston, 1988). It is the broadband equivalent of HNR, applicable across the full spectrum.	Low flatness distinguishes strongly tonal howls; high flatness distinguishes noisy, broadband bark-growl calls. A key feature for automated classification of jackal call types.

Variable	Definition / Meaning	Theoretical Basis	Significance in Bioacoustic Study
spec_entropy_mean	Mean spectral entropy — information-theoretic measure of spectral uncertainty; low entropy = tonal/structured; high entropy = noisy/unpredictable.	Spectral entropy is derived from Shannon's information theory (Shannon, 1948) applied to the normalised power spectrum. It quantifies spectral disorder.	Complements spectral flatness in distinguishing tonal from noisy calls. In bioacoustics, entropy-based features are robust to amplitude variation, making them reliable across field recording conditions.
MFCC MEANS — SPECTRAL SHAPE (COEFFICIENTS 1–13)			
mfcc1_mean	Mean of MFCC coefficient 1 — the first Mel-Frequency Cepstral Coefficient, primarily encoding overall spectral energy level (closely related to log energy).	MFCCs are derived from the Discrete Cosine Transform of the log mel-filterbank spectrum (Davis & Mermelstein, 1980). MFCC1 captures the dominant overall spectral shape component.	MFCC1 is the dominant energy-related coefficient. In jackal calls, it reflects overall call loudness and spectral density, useful for separating high-energy territorial calls from soft contact calls.
mfcc2_mean	Mean of MFCC coefficient 2 — encodes the spectral tilt or slope from low to high frequencies; distinguishes calls with rising vs. falling spectral energy.	MFCC2 captures the first derivative of spectral shape along the mel scale (Davis & Mermelstein, 1980). It is highly sensitive to the spectral tilt of the sound.	Differentiates calls dominated by low-frequency energy (negative MFCC2) from those with balanced or high-frequency energy (positive MFCC2). Key for separating growls from howls.
mfcc3_mean	Mean of MFCC coefficient 3 — encodes the spectral curvature, capturing whether the spectrum has a mid-frequency peak or valley.	MFCC3 reflects the second-order spectral shape (Davis & Mermelstein, 1980), sensitive to mid-frequency spectral humps or troughs.	Contributes to distinguishing call types with similar centroid but different mid-frequency structure. In multi-coefficient discriminant analysis, MFCC3 often loads on the second principal component.
mfcc4_mean	Mean of MFCC coefficient 4 — encodes higher-order spectral shape detail at finer frequency resolution.	MFCC4 captures progressively finer spectral modulations (Davis & Mermelstein, 1980). Its contribution to overall signal character decreases compared to lower coefficients.	Provides additional spectral discrimination power beyond MFCC1-3. Useful in speaker/individual recognition where fine spectral differences between individuals are relevant.
mfcc5_mean	Mean of MFCC coefficient 5 — encodes fine-scale spectral texture, beginning to capture formant interaction effects.	MFCC5 encodes finer spectral nuances and begins to reflect formant spacing patterns (Davis & Mermelstein, 1980).	Contributes to individual-identity encoding in multi-coefficient analyses. In machine learning classifiers for jackal call types, MFCC5 adds incremental discriminative value.
mfcc6_mean	Mean of MFCC coefficient 6 — captures even finer spectral detail, increasingly reflecting subtle harmonic structure.	Higher MFCCs (6 and above) encode progressively finer spectral modulations, capturing subtle harmonic spacing and resonance patterns (Davis & Mermelstein, 1980).	At MFCC6 and above, coefficients mainly contribute to fine-grained spectral texture differentiation. In ensemble with lower MFCCs, they improve automated call classification accuracy.
mfcc7_mean	Mean of MFCC coefficient 7 — encodes fine spectral modulations at high cepstral quefrencies.	MFCC7 captures high-quefrency cepstral detail (Davis & Mermelstein, 1980). Its biological interpretation is less direct than lower coefficients but contributes statistically to signal discrimination.	Used in classification algorithms to capture residual spectral variation not covered by lower coefficients. Together, MFCCs 1-13 provide a compact, perceptually weighted representation of call spectra.
mfcc8_mean	Mean of MFCC coefficient 8 — high-order cepstral coefficient encoding very fine spectral modulation.	At MFCC8, the spectral modulation captured is at very fine frequency resolution (Davis & Mermelstein, 1980), approaching the limits of perceptual relevance.	Retains residual discriminative value in large-dataset machine learning. For jackal call classification, MFCCs 8-13 are typically included as a block rather than interpreted individually.
mfcc9_mean	Mean of MFCC coefficient 9 — high-order cepstral feature encoding subtle spectral variation.	MFCC9 encodes spectral detail at high quefrency, primarily reflecting fine harmonic structure and microphone/environmental filtering	Contributes marginally to call type discrimination on its own; becomes meaningful in combination. In PCA of MFCC feature sets, higher coefficients often cluster on

Variable	Definition / Meaning	Theoretical Basis	Significance in Bioacoustic Study
		artefacts (Davis & Mermelstein, 1980).	components capturing recording variability.
mfcc10_mean	Mean of MFCC coefficient 10 — very high-order cepstral feature.	MFCC10 operates at the high quefrency range of the cepstrum (Davis & Mermelstein, 1980). It is increasingly influenced by recording channel characteristics.	In field bioacoustics with variable recording conditions, MFCCs 10-13 should be interpreted cautiously. They can capture environmental or equipment variation as much as biological signal.
mfcc11_mean	Mean of MFCC coefficient 11.	MFCC11 encodes the highest-frequency spectral modulations resolvable in the cepstral domain (Davis & Mermelstein, 1980).	Best used as part of a full 13-coefficient vector in classification contexts. Individual biological interpretation is limited; its value is as part of the complete spectral representation.
mfcc12_mean	Mean of MFCC coefficient 12.	Second highest MFCC in this study. Captures near-maximum quefrency cepstral information (Davis & Mermelstein, 1980).	Mainly used to ensure the MFCC feature vector captures the full span of spectral modulation. Useful in deep learning and SVM-based call classification pipelines.
mfcc13_mean	Mean of MFCC coefficient 13 — the highest-order coefficient in this study, encoding the finest spectral detail.	MFCC13 is the final coefficient in the standard 13-coefficient MFCC representation (Davis & Mermelstein, 1980), completing the compact spectral summary.	Completes the 13-coefficient mean feature vector. Together, mfcc1_mean to mfcc13_mean provide a compact but comprehensive encoding of the average spectral shape of each jackal call recording.
MFCC STANDARD DEVIATIONS — TEMPORAL DYNAMICS (COEFFICIENTS 1–13)			
mfcc1_sd	Standard deviation of MFCC coefficient 1 across time frames — quantifying temporal variability of overall spectral energy.	MFCC temporal standard deviations (delta features) encode how much the spectral envelope changes over time (Furui, 1986). They complement mean MFCCs in characterising call dynamics.	High MFCC1 SD indicates strongly amplitude-modulated calls with varying energy over time. Distinguishes rhythmically patterned calls from steady-state tonal calls in jackal repertoires.
mfcc2_sd	Standard deviation of MFCC coefficient 2 — quantifying temporal variability of spectral tilt.	MFCC2 SD captures dynamic shifts in spectral slope during the call (Furui, 1986). It encodes whether the call's spectral balance shifts over time.	High values indicate calls that transition from low-frequency-dominant to high-frequency-dominant segments, or vice versa. Useful for characterising frequency-swept or modulated calls.
mfcc3_sd	Standard deviation of MFCC coefficient 3 — variability of mid-frequency spectral curvature over time.	MFCC3 SD encodes temporal changes in the spectral curvature of the call (Furui, 1986).	Reflects dynamic reshaping of the mid-frequency spectral envelope during the call. Useful for distinguishing multi-segment calls from uniform, steady-state calls.
mfcc4_sd	Standard deviation of MFCC coefficient 4 — temporal variability of higher-order spectral shape.	MFCC4 SD captures dynamic changes in fine spectral modulation (Furui, 1986).	Contributes to the temporal dynamics feature set. Combined with lower MFCC SDs, it helps characterise the overall degree of spectral change within a call.
mfcc5_sd	Standard deviation of MFCC coefficient 5 — temporal variability of formant-interaction-related spectral features.	MFCC5 SD encodes changes in fine spectral texture over call duration (Furui, 1986).	Adds to the characterisation of dynamic spectral variation within calls. Useful for separating calls with stable vs. variable fine spectral structure.
mfcc6_sd	Standard deviation of MFCC coefficient 6 — temporal variability of fine harmonic spectral texture.	MFCC6 SD captures time-varying harmonic spacing fluctuations within the call (Furui, 1986).	Provides incremental temporal dynamics information. In classification pipelines, MFCC SDs (1-6) are generally more informative than those of higher coefficients.

Variable	Definition / Meaning	Theoretical Basis	Significance in Bioacoustic Study
mfcc7_sd	Standard deviation of MFCC coefficient 7 — temporal variability of high-quefrency spectral modulation.	MFCC7 SD encodes variability at fine spectral modulation scales across time (Furui, 1986).	Contributes to the upper-order temporal dynamics feature set. Useful in ensemble classifiers trained on full MFCC SD vectors.
mfcc8_sd	Standard deviation of MFCC coefficient 8 — temporal variability of very fine spectral detail.	MFCC8 SD captures high-quefrency temporal variation (Furui, 1986). Its biological signal content is limited.	Primarily useful in data-driven classification contexts. In field recordings with environmental noise, MFCC8 SD should be interpreted cautiously alongside recording quality metrics.
mfcc9_sd	Standard deviation of MFCC coefficient 9 — temporal variability of high-order spectral features.	MFCC9 SD encodes the highest-resolution temporal spectral dynamics (Furui, 1986) still retaining some biological relevance.	Adds marginal discriminative value in ensemble feature vectors. Best evaluated in the context of cross-validation results rather than individual coefficient inspection.
mfcc10_sd	Standard deviation of MFCC coefficient 10 — high-order temporal spectral variability.	MFCC10 SD captures temporal variation at high quefrency — largely overlapping with channel and environmental variability (Furui, 1986).	Should be interpreted with caution in field bioacoustics. It can reflect recording environment differences (reverberation, wind noise) as much as biological call variation.
mfcc11_sd	Standard deviation of MFCC coefficient 11.	MFCC11 SD is among the highest-order temporal dynamics features (Furui, 1986). Its signal is heavily influenced by non-biological sources in field conditions.	Use primarily in fully controlled recording conditions or after channel normalisation. In ensemble classification, contributes to the completeness of the feature vector.
mfcc12_sd	Standard deviation of MFCC coefficient 12.	MFCC12 SD captures near-maximum quefrency temporal variation (Furui, 1986).	Useful in automated classification pipelines where all 13 MFCC SDs are included as a feature block. Biological interpretation is minimal at this coefficient level.
mfcc13_sd	Standard deviation of MFCC coefficient 13 — the final and highest-order temporal dynamics feature in this study.	MFCC13 SD completes the 13-coefficient temporal dynamics vector (Furui, 1986). Together with mfcc1_sd to mfcc12_sd, it provides a full delta-MFCC representation.	Completes the MFCC SD feature block. The full set of 13 MFCC means and 13 MFCC SDs (26 features total) provides a compact, perceptually grounded spectral and temporal characterisation of each jackal call recording.

APPENDIX II

SOCIO-ECOLOGICAL STUDY

Social Representation of the Golden Jackal

A Rural–Urban Comparative Field Questionnaire

Theoretical framework	**Study parameters**
Moscovici Social Representation Theory (1961/1984) Abric Central Core / Peripheral System (1993)	Target species: Canis aureus indicus Groups: Rural(buffer zone) & Urban(Wildlife Professionals)

ETHICAL PREAMBLE — read aloud before beginning

This study is purely academic. Your participation is voluntary and you may stop at any time. All responses are anonymous and will not be shared with any authority or official. There are no right or wrong answers — your personal knowledge and experience is what matters.

Respondent ID: _____	Date: _____

Section 0 Respondent Profile

0.1

Study group

○ Rural — buffer zone / forest fringe	○ Peri-urban	○ Urban — Wildlife/Ecology/Conservation professionals

0.2

Approximate age group

○ 18–25	○ 26–40	○ 41–60
○ 60+		

0.3

Gender (self-identified)

○ Male	○ Female	○ Other / Prefer not to say

0.4

Highest education completed

○ No formal schooling	○ Primary (up to class 5)	○ Secondary (class 6–10)
○ Higher secondary	○ Graduate / postgraduate	

0.5

Primary livelihood

○ Pastoralism / livestock herding	○ Agriculture	○ Forest-based (collection, labour)
○ Service / salaried employment	○ Business / trade	○ Student
○ Daily Labour	○ Wildlife/Ecology/Conservation professional	○ Other

0.6

How many years have you lived in or near this area?

○ Less than 5 years	○ 5–15 years	○ 15–30 years
○ Lifelong / born here	○ Seasonal migrant	

0.7

Have you ever personally seen or heard a jackal?

○ Yes, many times	○ Yes, a few times	○ Yes, once or twice
○ Never seen, but heard calls	○ Never — only know from media / stories / books	

0.8

Where does your knowledge of jackals mainly come from? (choose top 2)

○ Personal experience	○ Family / community oral knowledge	○ TV / film / documentary
○ Social media	○ News (print or digital)	○ Books / formal education
○ Religious / mythological tradition	○ Forest department / NGO	

Section 1 Free Listing

1.1 Core free listing task

Say to respondent: "I am going to say one word. Please tell me **all** the words, images, or ideas that immediately come to your mind. Say as many as you can, in any order. Do not censor yourself. The word is: **JACKAL** "

1st	2nd	3rd	4th	5th
6th	**7th**	**8th**	**9th**	**10th**

_____	_____	_____	_____	_____

1.2 Importance ranking

Say: "Now look at all the words you said. Which 3 feel most important to you when you think of jackals?"

1st Most important: _____

2nd most important: _____

3rd most important: _____

Section 2 Centrality Check

2.1 Replaceability probe

Read back the three most important words from 1.2. For each:
"If jackals did not have this quality, would your understanding of jackals completely change?"

Word	Yes - completely changes	Partly changes	No - stays the same
1. _____	○	○	○
2. _____	○	○	○
3. _____	○	○	○

2.2 Prototypicality rating (1 = not at all characteristic, 5 = completely characteristic)
Rate each quality: how characteristic is it of jackals?

Statement	1	2	3	4	5
Dangerous to people	○	○	○	○	○
Dangerous to livestock	○	○	○	○	○
Wild / untamed	○	○	○	○	○
Cunning / clever	○	○	○	○	○
Ecologically useful	○	○	○	○	○
Worthy of legal protection	○	○	○	○	○
A scavenger / cleaner of the environment	○	○	○	○	○
Associated with bad omens or ill luck	○	○	○	○	○
Similar to a domestic dog	○	○	○	○	○
Naturally belongs in this landscape	○	○	○	○	○

Section 3 Attitude Scale

Rate each statement: 1 = Strongly disagree 2 = Disagree 3 = Neutral 4 = Agree 5 = Strongly agree

Statement	1	2	3	4	5
I feel afraid when I think about jackals near my home	○	○	○	○	○
Jackals are important for the health of the environment	○	○	○	○	○
(R) Jackals cause more harm than good to people like me	○	○	○	○	○
I would be comfortable if jackals lived in a forest near my area	○	○	○	○	○
Jackals should be legally protected	○	○	○	○	○
(R) Jackals are a nuisance that should be removed	○	○	○	○	○
I feel a sense of connection or respect for jackals	○	○	○	○	○
Hearing jackals call at night makes me feel anxious	○	○	○	○	○
People living near jackals deserve government support	○	○	○	○	○
I trust scientists and conservationists to manage jackals fairly	○	○	○	○	○

Section 4 Anchoring

4.1 Primary anchor selection

Present the eight categories below. Ask: "Which best describes how you think of jackals? You may choose more than one."

Pest / vermin Needs to be controlled, removed, or exterminated	**Predator** Threatens livestock or people; actively feared	**Scavenger / cleaner** Clears carcasses; serves a useful ecological function	**Forest animal** Belongs in the wild; part of the natural order
Mythological figure Linked to folklore, omens, religious or folk stories	**Endangered wildlife** Protected species requiring conservation attention	**Dog-like animal** Similar to domestic dogs; familiar and non-threatening	**Unknown / unseen** Never encountered; no clear mental category

4.2

Why did you choose that category? What experience or knowledge led you to think of jackals that way?

_____

4.3

Is a jackal more like a wolf, a fox, a stray dog, or something else entirely? Why?

Section 5 Objectification & Figurative Nucleus

5.1 Semantic differential (Osgood scale — circle position 1 through 5)

1 = completely the left quality | 3 = neutral | 5 = completely the right quality

Dangerous *Harmless*	1	2	3	4	5
Ugly *Beautiful*	1	2	3	4	5
Weak *Powerful*	1	2	3	4	5
Useless *Useful*	1	2	3	4	5
Unnatural *Natural*	1	2	3	4	5
Enemy *Companion*	1	2	3	4	5
Repulsive *Appealing*	1	2	3	4	5
Unpredictable *Predictable*	1	2	3	4	5

5.2

If you had to describe a jackal using only one image, scene, or story — something that captures what a jackal really is — what would it be?

5.3

What is the first thing that comes to mind when you hear a jackal call at night?

Section 6 Behavioural Intention

6.1 Scenario responses

Ask the respondent what they would do, or what they think should happen in each scenario.

Scenario A

A jackal is seen near your settlement or neighbourhood at dusk. What would you do?

○ Ignore it — leave it alone	○ Watch from a safe distance	○ Chase it away with noise
○ Alert neighbours / community	○ Call the forest department	○ Try to harm or trap it

Scenario B

A jackal kills a goat belonging to your neighbour. What should happen to the jackal?

○ Nothing — it is natural behaviour	○ Compensation should be paid to the neighbour	○ The jackal should be relocated
○ The jackal should be culled / removed	○ I don't know	

Scenario C (urban only — skip for rural)

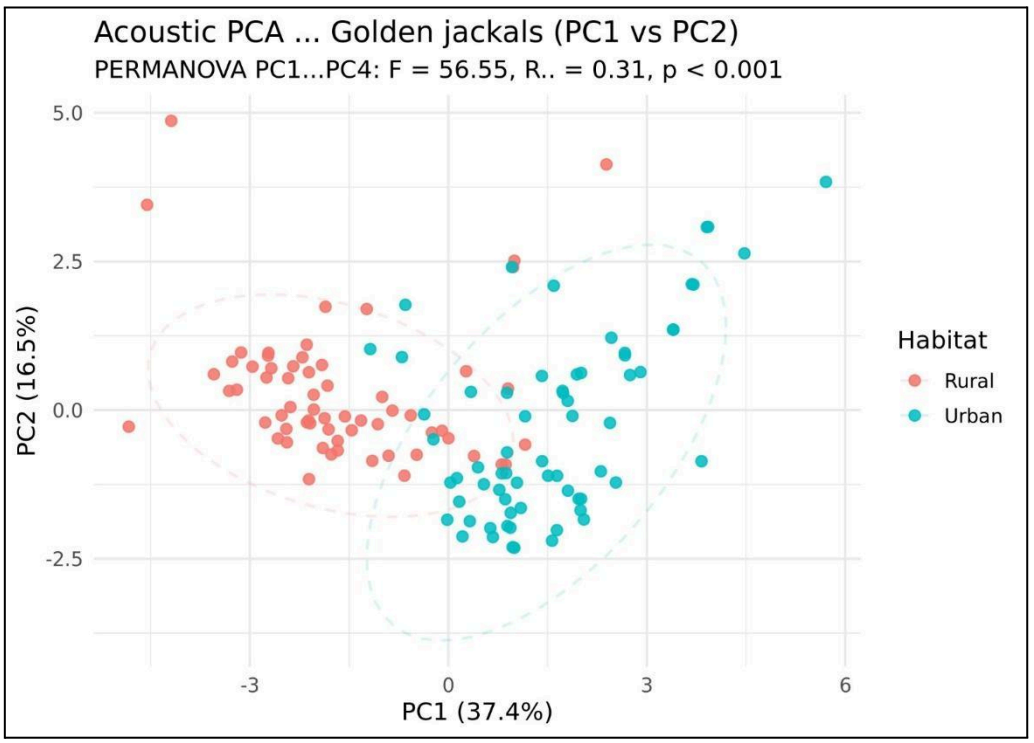
Yo

○ Leave them undisturbed	○ Create safe corridors for them	○ Relocate them to a forest
○ Control the population	○ No opinion	

6.2 Closing narrative — always end the interview here

"Is there anything you would like to add about jackals, or about how you think people in your community see them?"

Appendix III



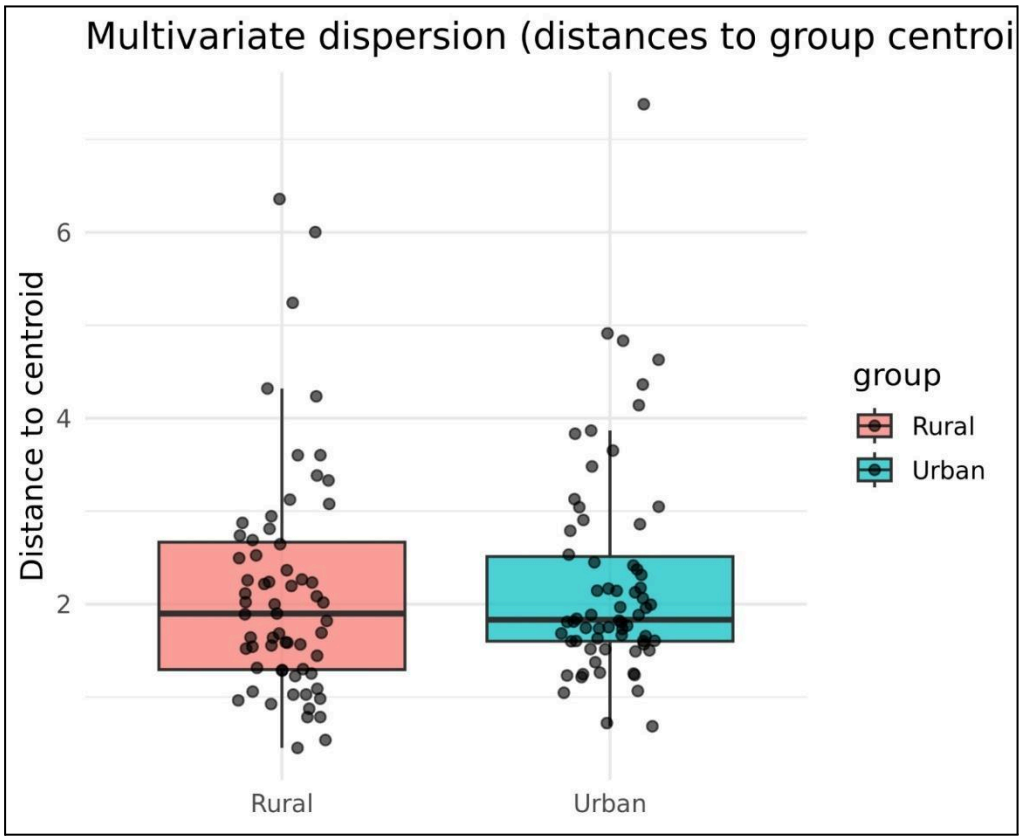


Figure: Multivariate dispersion and PERMANOVA on PC1-PC4 for rural and urban habitats