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RESEARCH PAPER

Coexistence of Wild Fauna in the City: A Case Study of the Golden Jackal (*Canis aureus* Linn.) in Central Ridge, Delhi

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Abstract: Rapid urbanization across the world has drawn attention to the unique state of urban woodlands. New Delhi is one of the world's most populous cities; yet, it harbours several woodlands that support a variety of wildlife. The persistence of mesopredators like the golden jackal (*Canis aureus* Linn.) in the city is intriguing and provides an opportunity to explore coexistence in an urban context. Using a combination of camera trapping and occupancy modelling, our study aims to understand the habitat use, distribution, and urban adaptations of the jackal in Delhi's Central Ridge Reserve Forest. Preliminary analysis shows extensive habitat use and sophisticated adaptations including adjustments in activity patterns in response to human activity and competition from feral dogs. The study also demonstrated behavioural adaptations, particularly in terms of foraging, denning, and coexistence with other species, which enable these urban populations of golden jackals to persist in the city. The study indicates the need for newer frameworks for conservation of synanthropic wild fauna that persist in calorie-rich urban environments.

Keywords: Urbanisation, Delhi Ridge, Golden Jackals, Mesopredator, Behavioural Adaptations, Synanthropic Fauna, Urban Adapters

1. INTRODUCTION

Urban ecosystems are unique combinations of the natural sphere, with abiotic and biotic components, and the anthroposphere, which exists as a

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result of the socio-politico-economic actions of humans (Endlicher *et al.* 2007; Gehrt *et al.* 2010). Human activities are central to the creation of new patterns and processes, leading to novel forms of nature in cities (Shochat *et al.* 2006). Urban landscapes have always hosted, and continue to cater to, a unique set of species and novel biological communities that are shaped by the loss of native species and the introduction of alien species (Grimm *et al.* 2015; Kowarik 2011). Urban ecology thus becomes a study of habitat fragmentation (Schilthuizen 2018). Most urban landscapes today are undergoing rapid compartmentalization into mosaics of areas constructed for residential, commercial, industrial, and transportation purposes, interspersed with green spaces (Venn and Niemelä 2004; Bateman and Fleming 2012; Forman and Alexander 1998). These landscapes may be composed of disconnected subpopulations or metapopulations of plants and animals that have limited interaction between them (Rodewald and Gehrt 2014; Andrén 1994; Bennett and Saunders 2010; Fahrig 2003).

Urban landscapes are fascinatingly heterogeneous, including niches that have resulted from the development of built infrastructure and modified natural areas (Thomas 2017; Schilthuizen 2018). These new habitats, some of which are abundant in resources, provide opportunities for species to optimize behaviourally and physiologically to these "super-rich patches" (Bateman and Fleming 2012; Prange *et al.* 2004). Several species continuously adapt to transforming city environments and undergo a process of "synurbization", taking advantage of novel opportunities in cities (Luniak 2004). Urban wildlife populations may therefore be significantly different from their counterparts in the wild, having distinctive life histories, behaviours, and physiological traits that enable them to navigate urban environments; but these differences are poorly understood (Rodewald and Gehrt 2014). Further, Blair (2001) suggests that species that are successful in urban settings—"urban adapters"—respond differently in terms of behavioural adaptations despite being challenged by a similar set of environmental factors.

Urban adapters demonstrate a wide array of responses to urban environmental conditions. Besides making evolutionary adaptations to altered environmental conditions, organisms are capable of non-evolutionary adaptations by adjusting their physiology, morphology, and behaviours (McDonnell and Hahs 2015). In the case of plants and microbes, physiological and genetic adaptations, which are well known and widely studied, dominate. In the case of animals, however, behavioural adaptations seem to play a major role. This could be the case because animals, being mobile, can avoid unfavourable environmental conditions by relocating. Behaviours that manifest as a result of such factors indicate which animals are more likely to survive in a given environment—"survival value" or adaptation (Tinbergen 1963; Dawkins 2008; McDonnell and Hahs 2015). These behavioural adaptations, whether innate or learned, are a product of genetic and environmental factors (Jensen 2007; Sol *et al.* 2013).

Among urban adapters, mesopredators or medium-sized predators are extremely flexible in terms of their behaviour, diet, and ability to adapt to highly fragmented and human-dominated landscapes (Ćirović *et al.* 2016; Crooks 2002). Mesopredators play an important role in urban ecosystems (Morell 2013) because of their position in the food chain (Hepcan 2012). The establishment of coyotes in cities in the United States (Gehrt 2007) and the expansion of golden jackals through Europe (Trouwborst *et al.* 2015) are compelling examples of mesopredator adaptations in urban environments. Although humans have made intensive efforts to control populations of canids such as red foxes, coyotes, golden jackals, and feral dogs, these species have managed to not only survive but thrive (MacDonald *et al.* 2019).

The focal species of this study—the golden jackal (*Canis aureus* Linn.)—is a mesopredator of the family Canidae and one of the most widespread canids across the globe (Markov 2012). Indian golden jackals form the oldest haplogroup in the world (Ibiş *et al.* 2015), with the northern and west Indian populations being the oldest genetic stock from which jackals radiated all over the planet after the Last Glacial Maximum (Yumnam *et al.* 2015). Presently, the golden jackal is listed as a species of Least Concern by the International Union for Conservation of Nature (IUCN) (Hoffmann *et al.* 2018). Through a recent amendment to the Wild Life (Protection) Act in 2022, the golden jackal has been given the highest level of protection in India as a Schedule I species (Government of India 2022).

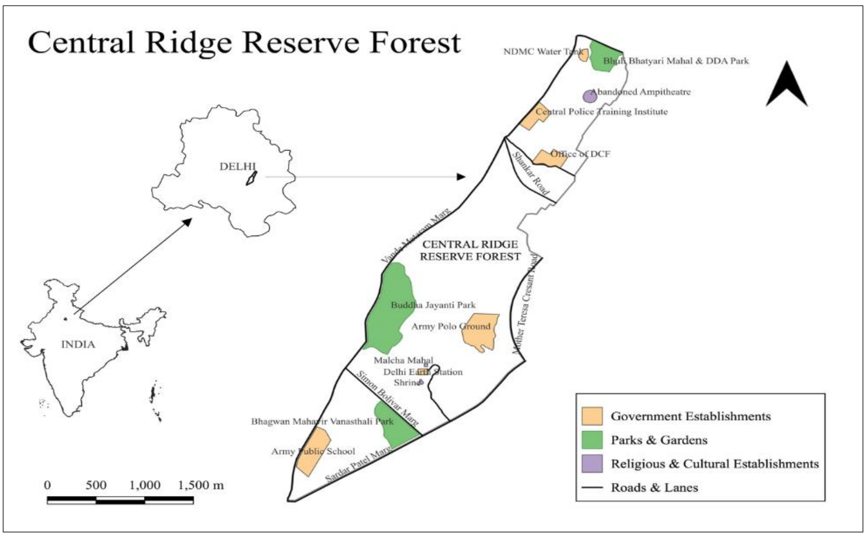
In Delhi, the golden jackal is found in parks and woodlands of the Delhi Ridge and has recently been sighted in other conservation areas such as the Yamuna Biodiversity Park (Gandhiok 2023). Golden jackal populations that thrived in most parts of the city a century ago are now restricted to the forest fragments of the Delhi Ridge and a few tracts of the floodplains. The rest of the land has been taken over by the built infrastructure of the National Capital Territory (NCT) of Delhi.

The objectives of this investigation are twofold: (i) to study the distribution and habitat use of the golden jackal in the Delhi Ridge, and (ii) to study the behavioural adaptations of the golden jackal and other common faunal species in the Ridge—specifically in terms of temporal and spatial responses to life in the city.

2. STUDY SITE

Spread over an area of 1,483 km^2 and with over 30 million residents, Delhi is the most populous city in India. The city is projected to become the most populous in the world, with a population of 39 million, by 2030 (United Nations 2019; Census of India 2011). Delhi is unique in its rich biogeographical heritage, and in comparison to other regions in the country, it has a remarkable number of trees and a large area of dense forests (Crowley 2015). Delhi's urbanization has historically been characterised by major landscape-level changes, modernization, sprawl, and the consequent transformation of its two major ecological features: the Aravallis and the Yamuna floodplains. Aravalli is the oldest mountain range in the country, traversing Gujarat, Rajasthan, Haryana, and Delhi (Varsha 2014). Although "ridge" is a colonial term used to describe the hilly topography of Delhi, when people speak of the Ridge, they are usually referring not to its rocky outcrops but its forests (Crowley 2015; Baviskar 2020).

Figure 1: Physical Layout of the Study Site



Source: Authors' analysis

Note: The study was conducted on 464 hectares (4.64 km^2) of the Central Ridge Reserve Forest, which is under the jurisdiction of the Department of Forests and Wildlife, Government of the NCT of Delhi.

The Central Ridge (formerly called the Southern Ridge) is a reserved forest spread over an area of 864 hectares (8.64 km^2), situated in the administrative centre of Delhi (Sud 2017; Varsha 2014). It was accorded protection in 1913 by British rulers under Section 4 of Act VII of the Indian Forest Act, 1878, through the appropriation and afforestation of the land of about 25 villages (then listed as 788 hectares) (Varsha 2014; Sud 2017; Crowley 2015). The present Central Ridge falls under the jurisdiction of a surprisingly large number of state agencies including the Department of Forests and Wildlife, the Indian Army, the Delhi Development Authority (DDA), the Central Public Works Department (CPWD), the New Delhi Municipal Corporation (NDMC), the Ministry of Home Affairs (MHA), the Municipal Corporation of Delhi (MCD), the Indian Railways, the Land and Development Office (L&DO), and the Sports Authority of India (Solanki 2014; Crowley 2015). As can be seen in Figure 1, the Central Ridge is subject to multiple land uses. The various state and private agencies occupying the Central Ridge often have competing agendas and policies, making the space highly contested and politicized (Sud 2017).

The principal vegetation type of the Ridge is northern tropical thorn forests (Champion and Seth 1968). The dominant tree groups found are Acacia and Mimosa, with naturally occurring populations of native tree species such as *Acacia leucophloea*, *Acacia nilotica*, *Butea monosperma*, *Anogeissus pendula*, *Diospyros montana*, *Cordia dichotoma*, *Cordia rothii*, and *Ehretia laevis*, and native shrubs such as *Grewia tenax* and *Capparis sepiaria* (Krishen 2006; Maheshwari 1963). As far as faunal species are concerned, golden jackals and rhesus macaques (*Macaca mulatta*) are commonly seen in large numbers, especially at feeding sites—locations in the Ridge where people come to feed animals. Sizeable populations of feral cattle (*Bos indicus*) and feral pigs (*Sus domesticus*) are also frequently spotted at these feeding sites. Other wild species that are observed include nilgai (*Boselaphus tragocamelus*), Indian hare (*Lepus nigricollis*), common palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*), Indian grey mongoose (*Urva edwardsii*), and several other species of rodents, reptiles, amphibians, and birds, including the commonly occurring Indian peafowl (*Pavo cristatus*) (ZSI 1997).

3. METHODOLOGY

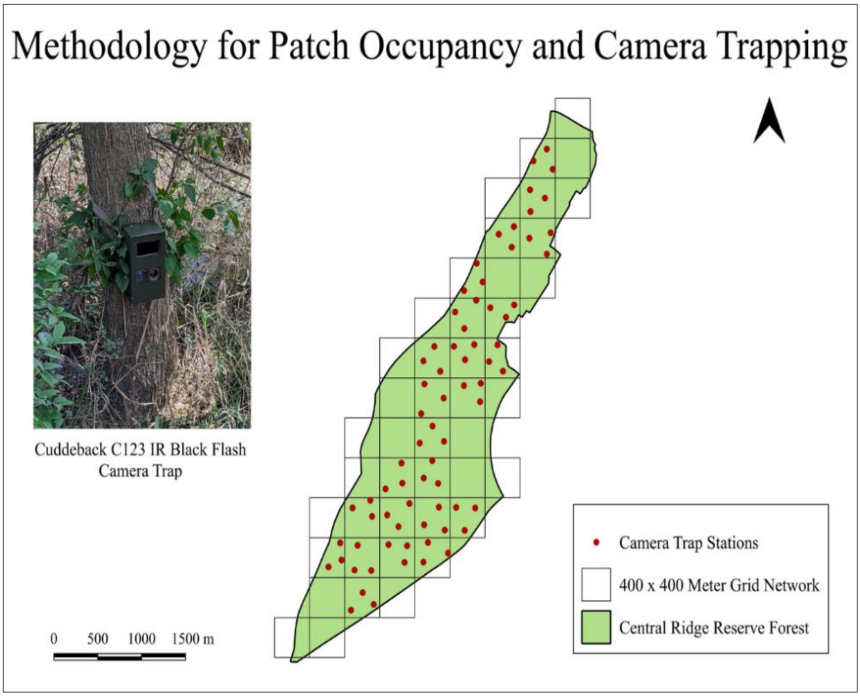
In pursuance of the objectives of our study on golden jackals and other associated faunal elements, we developed a study design that used a mixed methods approach, including a grid-based design, systematic sampling, the use of camera traps, occupancy/habitat use analysis, quantitative estimation of habitat variables or covariates, direct and indirect observation of animal behaviours, and analysis of secondary data.

3.1 Camera Trapping

Camera traps can be used to document species' presence in an area and to study activity patterns and certain aspects of behaviour. Camera trap surveys are extensively used in wildlife surveys and have been standardized to fit into statistical models for population studies (McCallum 2013; Rowcliffe and

Carbone 2008). Besides documenting species' presence and obtaining information on activity patterns and habitat preferences, camera traps can allow for estimating density and occupancy when used in scientifically robust, inferential sampling studies (Rovero *et al.* 2010).

Figure 2: Grid Network and Placement of Camera Trap Stations in the Central Ridge Reserve Forest



Source: Authors' analysis

Our camera trapping study design incorporated standard methods and recommendations as per Nichols *et al.* (2011). The study site was overlaid with 400 × 400 m grids, and each grid was considered a sampling unit. Grids that had 40% or more of built-up area were excluded from the sampling, resulting in 24 grids. A tracks and signs survey using the line transect method was conducted to find suitable spots to set up camera traps within each grid. Prior knowledge of golden jackal ecology and behaviours (i.e., preferred habitat, den characteristics, and visual appearance of spoor and scat) also helped with locating potential camera trap stations (Ancrenaz *et al.* 2012).

To maximize the probability of detecting a jackal in a grid, we deployed three camera traps per grid. As such, the entire study site had 72 camera trap stations (Figure 2). The study used 10 units of the Cuddeback 123 IR black flash camera trap—a passive sensor infrared camera system. All camera traps were operational for approximately 24 hours over three surveys. After three months of camera trapping, the survey effort amounted to a total of 5,184 camera trap hours (24 hours × 72 camera trap stations × 3 repeated surveys).

3.2 Patch Occupancy/Habitat Use

Estimating population parameters such as abundance or density has long been the focus of animal population studies (O'Connell and Bailey 2011). However, estimating parameters such as abundance requires that individuals are identifiable (by coat colour and/or pattern) to keep accurate records of the number of encounters for each animal (Mackenzie and Nichols 2004). The basic sampling protocol commonly used for occupancy estimation involves visiting sites and spending time in each one, looking either for individuals of the species of interest or for evidence that the species is present (Mackenzie *et al.* 2006). Mackenzie *et al.* (2006) developed models to estimate site occupancy and detection probability—the probability of detecting at least one individual of a species on one sampling occasion, given that the species is present in the sampling area—based on repeated presence/absence surveys of multiple sites.

Our study was based on the single-season occupancy modelling approach designed by Mackenzie *et al.* (2006). We used camera traps to establish the presence/absence of the golden jackal in the sampling grids. Occupancy and detection probability were modelled by coding photographic count data in a binary (1/0) format, describing detection (1) or non-detection (0) of the animal during the three repeated surveys. Due to the paucity of baseline data and home range of jackals in the urban setting, the results of our patch occupancy study are being interpreted as "habitat used" instead of "patch occupied" (Mackenzie and Royle 2005)[1].

The probability of occupancy or habitat use (ψ or psi) was modelled as a function of site-specific covariates or spatial variables, such as tree density, shrub density, dominant vegetation, and normalized difference vegetation index (NDVI), to make an inference about factors determining the golden jackals' habitat use. Meanwhile, detection probability (p) was modelled as a function of site-specific covariates, such as tree density and shrub density, and survey-specific covariates or temporal variables, such as maximum and

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[1] The 400 m x 400 m size we fixed for the sampling units was based on observations and not based on recorded home range data for urban conditions. Therefore, this assumption had to be relaxed by interpreting results not as patch 'occupancy' but as patch 'use' (Mackenzie and Royle, 2005), or habitat use.

minimum temperatures, to determine how likely a species is to be detected when present (Sollmann 2018).

The single-season occupancy modelling approach and detection history were analysed using the package unmarked in R (Fiske and Chandler 2011) to generate maximum likelihood estimates for occupancy/habitat use and detection probabilities. Further, all possible combinations of site-specific and survey-specific covariates as influences on occupancy/habitat use and detection probabilities were modelled using the logit link function. For the interpretation of results, only model(s) with the least AIC (Akaike information criteria) were considered (Burnham and Anderson 2002).

3.3 Behavioural Adaptations of Golden Jackals

The section below outlines methods used to survey specific behavioural adaptations examined in the study, including temporal activity patterns, foraging, and denning.

3.3.1 Temporal Activity Patterns

Temporal activity data for golden jackals in the Central Ridge Reserve Forest were derived from camera trap images that were obtained from the patch occupancy or habitat use study of the species. Additionally, we obtained data on the temporal activity of feral dogs and humans, since these species seem to influence golden jackal activity, especially in the urban context.

Images were analysed for the presence of golden jackals, feral dogs, and humans, and when detected, the timestamps were recorded. Once all this data was collected, following the method used by Gil-Fernández *et al.* (2020), we employed the package overlap in R (Meredith and Ridout 2014) to determine the overlap between two activity patterns based on kernel density estimates. We compared the temporal activity patterns of jackal–dog, jackal–human, and dog–human across the study site. To interpret the overlap in activity patterns, we used the overlap estimator Dhat4, which is ideal for samples with >50 observations per species.

Temporal activity data for all other species found in the Central Ridge Reserve Forest was also derived from the same camera trapping exercise. Besides golden jackals, feral dogs, and humans, we detected the common palm civet, small Indian civet, rhesus macaque, feral cattle, feral pig, Indian peafowl, Indian hare, Indian grey mongoose, and nilgai. Detections of each species were analysed and activity pattern graphs were generated using the package overlap in R.

3.3.2 Foraging Behaviour

Golden jackal foraging behaviour, especially for anthropogenic food, was directly and indirectly observed at a major feeding site in the Central Ridge Reserve Forest. Feeding sites are locations around the forest where people come to feed the animals, although not jackals specifically. People usually bring chapati, bread, grains, and fruits that are tossed away or kept on the ground to feed the animals. A variety of animals—macaques, cows, pigs, dogs, and jackals—congregate at these locations during feeding sessions.

We used opportunistic photographs and video clips, as well as direct visual sightings that were obtained throughout the study period and across all seasons, to understand the foraging behaviour of golden jackals at the feeding site. Using a Nikon P900 ultrazoom handheld camera, we captured the feeding behaviour of the animal. We used binoculars for direct visual sightings, while also making note of behavioural information. Our camera trap data facilitated an analysis of foraging for naturally occurring foods. Whenever possible, we conducted interviews with people who visited the Ridge and feeding site to offer food to the animals, to learn about their interactions with jackals and to gather other anecdotal information.

3.3.3 Reproduction and Denning Behaviour

Data on the denning behaviour of golden jackals was collected using the focal-group sampling method (Altmann 1974; Dawkins 2008). Focal-group sampling involved focusing on one family unit of the target species, recording everything they were doing, and generating statistics that were recorded as a single data point among a series of observations (see Dawkins 2008). Dens were opportunistically encountered during the fieldwork, and camera traps were deployed at active den sites. During our fieldwork in the Central Ridge Reserve Forest, we located two dens (Figure 6), one of which was occupied for consecutive seasons. The first den (henceforth D1) was located on 30 April 2022, and the second den (henceforth D2) was first located on 25 May 2022 and was abandoned and occupied again on 20 May 2023. Extensive data collection on denning behaviour was possible only for D2 from 25 May 2022 to 28 June 2022. The survey effort for D2 amounted to 22 calendar days or, more precisely, 415 camera trap hours.

3.4 History and Management of the Ridge

In addition to the primary survey, we consulted secondary sources to understand the history and management of the Delhi Ridge. These sources included archival records; popular articles in print and electronic media; reports of non-governmental organizations (NGOs); gazettes; planning documents such as the Delhi Master Plan; annual reports of government departments, the National Green Tribunal (NGT), and the Ridge Management Board; and other published work on regional history.

4. RESULTS

The results of our observations on the golden jackal's habitat use, temporal activity patterns, foraging behaviours, reproduction and denning, and the implications of the history of management of the Delhi Ridge, are presented in the following section.

Table 1: Comparison of Models to Explain Golden Jackal Habitat Use in the Central Ridge Reserve Forest

Model	K	AICc	ΔAICc	AICc Weight	Model Likelihood
psi (.), p (.)	2	80.85	0.00	0.27	1.00
psi (.), p (tree den.)	3	82.35	1.50	0.13	0.47
psi (.), p (max. temp.)	3	83.28	2.43	0.08	0.29
psi (.), p (min. temp.)	3	83.41	2.56	0.08	0.27
psi (.), p (shrub den.)	3	83.44	2.59	0.07	0.27
psi (dist. road), p (.)	3	83.48	2.63	0.07	0.26
psi (tree den.), p (.)	3	83.48	2.63	0.07	0.26
psi (shrub den.), p (.)	3	83.48	2.63	0.07	0.26
psi (dom. veg.), p (.)	3	83.48	2.63	0.07	0.26
psi (NDVI), p (.)	3	83.48	2.63	0.07	0.26

Source: Authors' analysis

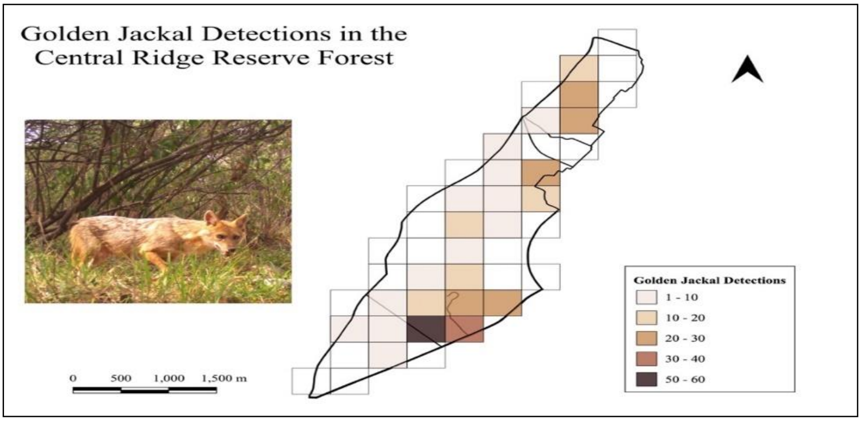
Notes: psi = occupancy; p = detection probability; (.) = null. Covariates: tree den. = tree density; shrub den. = shrub density; max. temp. = maximum temperature; min. temp. = minimum temperature; dom. veg. = dominant vegetation; NDVI = Normalized Difference Vegetation Index; dist. road = distance to the nearest road.

4.1 Patch Occupancy/Habitat Use

Analyses of our patch occupancy/habitat use data revealed that golden jackals in the Central Ridge Reserve Forest do not favour any particular habitat type, as they were detected in all our study grids or patches (Figure 3). While the naïve occupancy estimate was a perfect 1, indicating 100% usage of the study site by the golden jackal, the detection probability estimate was 0.78, i.e., there was a 78% chance of detecting the species given that it was present. However, the naïve occupancy does not consider imperfect detection. Yet, as evident in Table 1, the null model [psi (.), p (.)] is the top-ranking model, with the least AICc and maximum likelihood. In other words, none of the site-specific covariates (dominant vegetation, tree density, shrub density, NDVI, and distance to the nearest road) seem to influence the probability of a patch being used by the golden jackal. Similarly, the probability of detecting a golden jackal in our patches does not appear to be affected by survey-specific covariates such as maximum and minimum temperatures, and site-specific covariates such as tree density and shrub density. Although tree density seems to slightly influence the probability of detecting a golden jackal in a patch given its presence (ΔAICc: 1.50; model likelihood: 0.47), it is nowhere close to the best-performing model, i.e., the null model.

Among the 72 camera trap stations spread across the 24 study grids, golden jackals were detected at 60 stations (Figure 2). As can be seen in Figure 3, golden jackals were detected in all 24 grids, although varyingly. After 3 repeated surveys, we made 387 independent detections of golden jackals in the Central Ridge Reserve Forest, with 159 detections in the first survey, 126 in the second, and 102 in the third. Further, in the 387 independent detections, jackals were seen in trios in 11 instances, in pairs in 61 instances, and as solitary individuals in 232 instances. As expected, the highest number of captures were in grids near the feeding trail. We made 66 detections in one of these grids and 34 in the other. Of the remaining 22 grids that were surveyed for habitat use, 45.45% had 1–10 detections; 27.27% had 10–20; and 27.27% had 20–30.

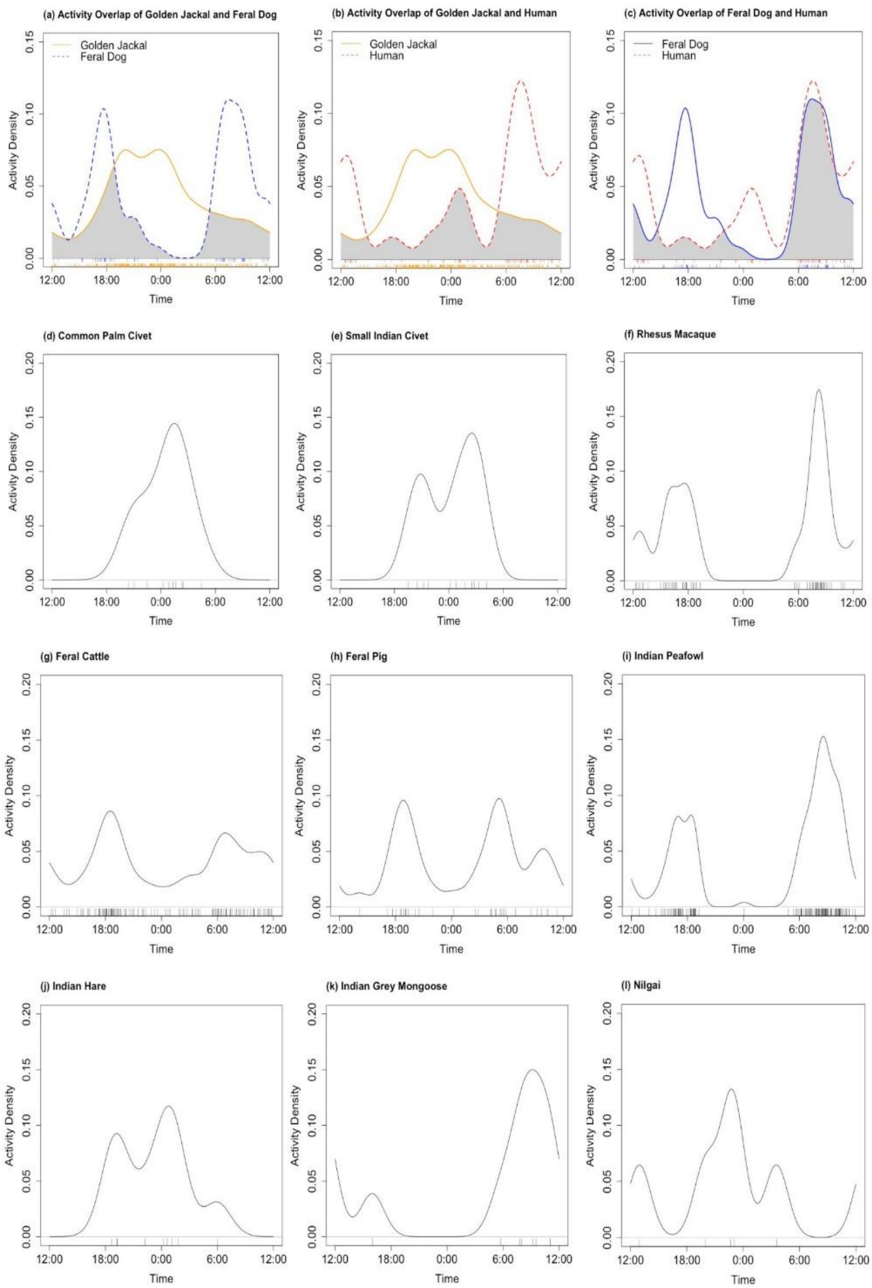
Figure 3: Golden Jackals Were Found in All of the 24 Study Grids; Some Grids Recorded More Detections than Others



Source: Authors' analysis

According to one of the few published studies on golden jackals in the urban Indian context, the population density of jackals in a 100-hectare (1 km²) golf club was 43 individuals (Sanyal *et al.* 2011; Gupta *et al.* 2016). A much lower

Figure 4: Temporal Activity Pattern Graphs for Different Species in the Central Ridge Reserve Forest



Source: Authors' analysis

Note: Graphs (a), (b), and (c) show the overlap in activity patterns between jackal and dog (53%); jackal and human (53%); and dog and human (66%), respectively. Graphs (d) to (l) depict the activity patterns of other species.

population density of approximately 15 jackals per km^2 was reported by Singh *et al.*, (2016) in the Keoladeo National Park, India. In the metropolis of Delhi, with its forest patches rich in anthropogenic resources and jackals showing extensive habitat use, our estimate of golden jackals in the 4.64 km^2 Central Ridge is 120–150 individuals, i.e., a population density of 26–32 individuals per km^2.

4.2 Temporal Activity Patterns

Results of the temporal activity pattern analysis of golden jackals, feral dogs, and humans in the Central Ridge Reserve Forest reveal a somewhat clear separation in temporal use between the three species (Figures 4a–c). While golden jackals use the same areas as feral dogs and humans, unlike the latter, golden jackals are most active at night, with activity peaking between 19:00 and 02:00. The mean overlap between golden jackal and feral dog activity was 0.53 (95% CI = 0.44–0.62); between golden jackal and human activity 0.53 (95% CI = 0.42–0.65); and between feral dog and human activity 0.66 (95% CI = 0.55–0.77). It is important to note, however, that the total number of sightings, depicted by the colour-coded bars at the base of the graphs, was highly variable. The highest number of sightings were of golden jackals; there were fewer sightings of feral dogs and humans.

When comparing the activity patterns of other faunal species (Figures 4d–l) found in the Central Ridge, we observed differences in their movement and activity. Temporal partitioning seems to exist between species—some are nocturnal, others diurnal, and still others exhibit cathemeral behaviours. The common palm civet and small Indian civet are primarily arboreal and rarely seen during the day; they come down to the forest floor at night in search of food. Therefore, the activity pattern graphs in Figures 4d–e are indicative of their nightly movements on the forest floor. The Indian hare is also predominantly active at night, although it can occasionally be sighted during the day (Figure 4j). In the case of the nilgai, the largest wild mammal found in the Ridge, sightings were restricted to 2 of the 24 grids, with most occurring after sundown. While occasional sightings of the nilgai are possible in the Central Ridge during the day, our data (Figure 4l) provides clear evidence of increased movement and activity at night. Our data suggests that species such as the common palm civet, small Indian civet, Indian hare, and nilgai are mostly nocturnal, at least in the Central Ridge.

Among the strictly diurnal species found in the Central Ridge are the rhesus macaque, Indian peafowl, and Indian grey mongoose. As can be seen in Figures 4f, 4i, and 4k, none of these three species show any significant activity from dusk to dawn (approximately 18:00–06:00). Similar to civets, macaques and peafowls exhibit a mix of arboreal and terrestrial behaviours; therefore, their activity pattern graphs only depict their movements on the forest floor. Feral cattle and feral pigs exhibit cathemeral behaviours, with both species being detected across the 24-hour cycle (Figures 4g–h). Both these species spend a significant amount of time close to feeding sites during the day, especially in the early mornings when feeders visit the forest. However, during the twilight hours and sometimes the night, they travel from one part of the forest to another. This is evidenced by the movement of large herds of cattle recorded by our camera traps.

4.3 Foraging Behaviour

While jackals are generally nocturnal (Patil and Jhala 2008), especially in the wilderness, in the Central Ridge Reserve Forest, they have also taken to opportunistic feeding on human-provisioned food during the day, especially in the early mornings. The food items golden jackals feed on in the Central Ridge include bananas, melons, bread, chapati, cake rusks (Figure 5), groundnuts, chickpeas, maize, and the occasional carcasses and offal material dumped by butchers. Jackals also drink water from the many troughs that line the feeding trail. Every morning, a few feeders come in cars with jerrycans of fresh water to refill the water troughs.

At feeding sites, jackals often expectantly wait for food to be handed to them by people who come in cars and on bikes; honking from these automobiles often incites curiosity, excitement, and hope among the animals. In one instance, we observed an adult jackal resting a little distance away from the main feeding trail, running to the trail at every sound of a car honking, and returning to its resting place once the car had passed. This happened at least three times after which the jackal moved away from its resting place. On several other occasions, jackals were seen trotting behind cars in the hope of receiving food. Such behaviours are a testament to the fact that jackals are opportunists and that they express certain novel behaviours in urban environments.

Our camera trapping data reveals the golden jackals' dependence on naturally occurring foods such as birds and insects; this is confirmed by other studies (e.g., Mukherjee *et al.* 2004; Baskaran *et al.* 2020). In India's Sariska Tiger Reserve, a scat analysis showed that 45% of the golden jackal's diet comprises mammals (of which 36% are rodents), 20% vegetable matter, 19% birds, 8% reptiles, and 8% invertebrates (Mukherjee 1998).

Figure 5: A Golden Jackal Grabbing Cake Rusks from the Pavement, Close to the Feeding Site

Source: Authors' compilation

4.4 Reproduction and Denning Behaviour

Our observations on the denning behaviours and reproduction of the golden jackal in the Central Ridge along with details on feeding behaviours during denning are presented in this section.

4.4.1 Denning Season

In India, golden jackals are typically monogamous, forming lifetime pair bonds and parenting offspring once a year, as the females are monestrous, i.e., they have one estrous cycle per year (Jhala and Moehlman 2004; Negi 2014). However, the social unit of jackals may also consist of "helpers"—offspring from the previous litter (11–20 months old) who help raise their younger siblings (Fuller *et al.* 1989). Carnivores such as wolves have highly regularized breeding and denning periods (Fuller *et al.* 2010), and as our research suggests, this may also be the case for jackals. Golden jackals begin exhibiting reproductive behaviour, i.e., mating, in February–March. This is followed by den selection/excavation in April–May. Finally, whelping occurs after a gestation period of 63 days, which often coincides with an abundance of food supply, i.e., at the beginning of the monsoon (Jhala and Moehlman 2004).

In 2022, D1 contained a single pup, which we estimated to be less than a week old when first detected. We triangulated this based on the fact that golden jackal pups are born blind and open their eyes only after about nine days (Jhala and Moehlman 2004). In the same season, D2 contained four pups, which we estimated to be between four to five weeks old when first detected. In 2023, D2 contained four pups which we estimated to be between three to four weeks old when first detected. Thus, there is a strong indication that, in all three cases, mating likely occurred in the last week of February and whelping in the last week of April.

4.4.2 Den Location and Characteristics

Canids are a group of mammals which do not build their own burrows as primary excavators do but are secondary modifiers that inhabit and maintain burrows built by primary excavators (Mukherjee *et al.* 2018). Dens are intrinsic to the lives of most wild canids and may be decisive factors in their abundance and distribution (Nurvianto *et al.* 2015). A denning site determines access to critical resources, provides protection from predators, acts as a safe haven from environmental vagaries, and offers conducive ambient conditions for the optimal development of offspring (Majumder *et al.* 2016).

Figure 6: Golden Jackal Dens in the Central Ridge Reserve Forest

Source: Authors' compilation
Note: (a) D1 contained a single pup in 2022; (b) D2 contained four pups each in 2022 and 2023.

As can be seen in Figure 6, D1 and D2 are very different types of natal shelters. D1 was located in a rocky habitat, with even elevation and characteristics of open-scrub forests. It was situated in a single-opening rock shelter in a crevice and had a shallow depression below the surface of the ground. D1 was surrounded on all sides by vegetation such as *Carissa spinarum*, *Abutilon indicum*, and grasses. The inside of the den had a bed of loose sand that probably provided cushioning for the pups. D2, on the other hand, was located in a rocky habitat, with uneven elevation and characteristics of a mixed forest. It was situated at the base of an *Azadirachta indica* tree and surrounded by other species such as *Holoptelea integrifolia* and *Ehretia laevis*, although the dominant vegetation in this patch was *Acacia catechu*. Some of the shrub species found around D2 were *Adhatoda vasica*, *Capparis sepiaria*, and *Carissa spinarum*. D2 also had a single opening, but unlike D1, it was under a living tree and had a mound-like appearance. At the entrance of the den were the roots of the tree, and the den was on slightly higher ground in relation to the natural objects in its immediate vicinity. D2 was located a few metres from the boundary wall along a main road and a busy intersection, but the breeding pair in both pup-rearing seasons (2022 and 2023) still chose this natal shelter.

4.4.3 Litter Size

Depending on their geographical location, golden jackals have varying litter sizes. In Tanzania, litter sizes vary from 1 to 8, the average being 5.7 (Kebede 2017), and in the Bhal region of India, litter sizes range from 2 to 5, with an average of 3.6 (Jhala and Moehlman 2004). In 2022, D1 contained a single pup, while D2 contained four pups. Similarly, in 2023, D2 contained four pups from the same breeding pair that occupied D2 in 2022. We also captured two other females and their respective pups on camera traps during the patch occupancy surveys. Both groups were led by the breeding female on foraging bouts. While one of the females had a single pup, the other had four. Therefore, with some level of confidence, we estimate the litter size of golden jackals in the Central Ridge Reserve Forest to range from one to four pups.

4.4.4 Feeding Behaviour

Canid pups consume only their mother's milk for the first few weeks after birth, after which, along with milk, they start consuming regurgitated food brought by the adults. According to MacDonald *et al.* (2019), regurgitation in canids is an evolutionary adaptation in monogamous social systems that facilitates parental care, alloparental care, and/or cooperative breeding. Regurgitating food provides an economical and safe way for parents and alloparents to bring large quantities of food to their pups (Moehlman 1987). During our research, we found that besides hunted food items such as small mammals (piglets, mongoose, etc.), golden jackal pups were also fed anthropogenic food such as chapati, bananas, and other high-calorie foods (Figure 7).

4.2 History and Management of the Ridge

In the last century, and more so in the post-Independence period, the urbanization processes of Delhi has led to a progressive fragmentation of the city's natural habitats; this fragmentation was particularly accelerated in the case of the Delhi Ridge (Baviskar 2018; Mohan 2002; Planning Commission 2009). As a remnant of the Aravalli mountains, which are rich in quartzite, the Ridge provided the rocks and other materials for the construction of Lutyens' Delhi. It also created an "evergreen background"—with the introduction of *Prosopis juliflora*—for the president's estate and several other government establishments built in and around the Central Ridge Reserve Forest (Mann and Sehrawat 2009; Bowe 2009; Baviskar 2018).

Figure 7: Golden Jackal Pups Were Provided a Combination of Natural and Anthropogenic Food Items by Both the Adults (Breeding Pair) and Sub-adults (Helpers); (a) Piglet; (b) Mongoose; (c) Chapati; (d) Regurgitated Banana

Source: Authors' compilation

In the post-Independence period, despite its status as a reserved forest, the Central Ridge was fragmented both for legal construction and illegal settlements, and its forests were cleared whenever there was a need to expand the city. Despite citizen movements in the 1980s, the fragmentation of the Ridge initially proceeded to create refugee settlements after the partition of India in 1947, and subsequently, to construct government establishments, military infrastructure, schools, and gardens, and to expand transport networks and various illegal encroachments (Baviskar 2018; Arora *et al.* 1991).

More recently, developmental activities and the building of roads, metro corridors, mega malls, residential complexes, corporate offices, luxury hotels, and farmhouses have all encroached upon forested land (Crowley 2015).

To address the issue of fragmentation of the Ridge, the Supreme Court of India had to intervene. Following the directions of the top court, in 1995, the Ridge Management Board was constituted with a mandate to protect and conserve the Ridge (Sinha 2014). However, when it comes to the management of the Ridge, state agencies in charge of the Ridge have always favoured the conversion of wild forests into semi-wild parklands (by cutting the undergrowth) or totally new parklands (by planting ornamental trees and shrubs after removing most of the original vegetation) (Arora *et al.* 1991). In other words, Ridge management has often meant turning wild forests into tamed parks (Crowley 2015). Presently, within the Ridge is a wildlife sanctuary, biodiversity parks, a citizens' forest, restoration projects, and a sizeable number of manicured parks (Sud 2017). Taming the forests became a mandate after the Ridge was perceived as a place of danger and criminal activity (Baviskar 2020). Further, although the Delhi Master Plan 2021 lays special emphasis on the conservation of the 77.77 km^2 Ridge, there are discrepancies between the area notified and the physical boundaries of the total area owned by various state agencies, the Forest Department, and the Ministry of Defence (DDA 2010).

The Ridge was once known for its abundant and diverse flora and fauna (Punjab Government 1883). However, pressure from hunting and massive fragmentation in the post-Independence era led to a sharp decline in wildlife populations, resulting in the local extinction of several species (Kumar 1997). For instance, archival records reveal that the golden jackal in Delhi was previously the target of post-colonial extermination campaigns and fight-to-the-finish drives because the animal was negatively portrayed as a rapidly multiplying species, a disturbance to the peace and tranquillity of the city, a danger to citizens, and a source of rabies for street dogs (The Times of India 1950). However, despite such campaigns, the rapid scale of urban expansion and the resulting fragmentation of natural habitats, the Ridge continues to harbour diverse fauna. Indeed, the species found in the Ridge have not formed habitat associations over a short span of time but gradually settled over a few centuries (Mann and Sehrawat 2009), in response to a changing, urbanising environment. However, being subject to certain combinations of ecological stresses, disturbances, structures, and functions (*sensu* Pickett *et al.* 1997), some native species that could not adapt to the urban landscape were exterminated or perished. Meanwhile, other native and non-native species that were able to adapt and coevolve, particularly in terms of behaviour, were able to survive.

5. DISCUSSION

One of the highlights of our research is the discovery of the ubiquitous presence and habitat use of the golden jackal in the Central Ridge Reserve Forest. Our findings reemphasize the fact that jackals are urban adapters, fitting into the spatial and temporal matrix of the city while performing their life functions. Although there were differences in habitat variables such as tree density, shrub density, dominant vegetation type, and NDVI across the study site, as well as the presence of multiple land uses—from parks and gardens to cultural, religious, and government establishments—the golden jackal was found in all 24 study grids. Typically, when examining wildlife habitat associations, a proper characterization of environmental and other potential explanatory variables or covariates at spatial scales pertinent to the species being researched is necessary (Niedballa *et al.* 2015). Yet from the outcomes of our study, it would seem that small habitat variations do not affect the distribution and habitat use of golden jackals in the urban context. While there were jackal detections in all our study grids, there were some grids, such as the one near the feeding trail, which made as many as 66 detections. However, the activity pattern of a particular species in a single season may not be a true reflection of its overall activity pattern across seasons. Indeed, several studies indicate that activity patterns are strongly influenced by factors such as seasonality, circannual rhythms (for instance, breeding and non-breeding seasons), diurnal variations, and vegetation structure (Iannarilli *et al.* 2021; Kays *et al.* 2020). However, within the constraints of the city, we find that habitat use and activity patterns of species do not demonstrate these typical relationships. We recognize, therefore, the need for a long-term study to monitor seasonal changes in activity patterns as well as the distribution and habitat use of the golden jackal in the Central Ridge. To make more accurate estimations of golden jackal numbers and deepen our understanding of foraging behaviour in the Central Ridge, further research involving radio-collaring, scat analysis, and genetic sampling is necessary.

There is a clear separation in time use between jackals, dogs, and humans in our Central Ridge Reserve Forest site. The co-occurrence of species, especially those belonging to the same guild, may lead to high niche overlap and the possibility of conflictual interactions such as competition or even exclusion (Gómez *et al.* 2018; Pascual-Rico *et al.* 2020). Studies have shown that, when dogs and native predators compete over human-derived materials, dogs may be more effective competitors with native carnivores (Vanak and Gompper 2009). But species may manage to avoid competition by evolving specialized ways of living, such as adopting a novel diet, occupying other habitats, or foraging at different times (Southern 1955). Therefore, temporal partitioning—using the same space at different times—facilitates the coexistence of species and access to available habitats and key resources (Gaynor 2018; Haswell 2020). In our study, jackals and feral dogs used the same habitat patches but separated their habitat use temporally, with jackals being predominantly nocturnal and dogs being predominantly diurnal.

Similarly, the majority of human detections occurred outside the peak activity hours of the golden jackal. Several studies have demonstrated that, where humans and wild animals coexist, animals adopt nocturnality to reduce contact with humans, who are mostly active during the day (Benítez-López 2018; Grinder and Krausman 2001). Our observations are consistent with studies (Gehrt 2007; Patil and Jhala 2008) that suggest that mesopredators such as coyotes and jackals become increasingly nocturnal as they come closer to human habitation and cities. Therefore, the shift to nocturnality among golden jackals in the Ridge is a coevolutionary outcome of a multispecies interaction.

Past studies on mesopredators have shown that the availability of a sustained supply of anthropogenic food in cities leads to a change in the home range behaviour of the mesopredators because they can spend less time foraging and simultaneously have access to highly nutritious food (Ryan and Partan 2014). Similarly, personal observations of early-morning jackal roadkills and other direct observations of jackals indicate that they move in relation to the spatial arrangement of resources such as food, water, and denning sites, and some individuals get killed while attempting to access these resources (Coffin 2007). Regardless, the novel behaviours of urban adapters point to their propensity to negotiate, learn, and adapt to the complex and dynamic nature of the city (Sinha and Barua 2020). This is consistent with our temporal activity pattern analysis which suggests that by following varied behavioural strategies, species have learnt to coexist in the small and fragmented habitats of the Ridge, synchronizing their life history strategies with what the city offers.

An important enquiry for biologists has been how some species are able to behaviourally adjust and adapt to cities while others are not, especially when resources are not a limiting factor (Lowry *et al.* 2013). The changes urban-dwelling wild canids have made to their reproductive behaviour and the successful raising of their offspring, both central to their life history strategies, are evidence that they are thriving in the city. Shrinking habitats results in the decline of denning sites (Majumder *et al.* 2016), leading mesopredators like jackals to take to human habitations and even abandoned or less used built infrastructure to bring up their offspring (Marks and Bloomfield 1999). One of the denning sites in this study was located close to a major traffic intersection, despite the noise from continuous vehicular movement and the blaring of horns. Such responses of urban adapters may also be an indication of their propensity for risk-taking behaviours, whereby they display a high disturbance tolerance or bold temperament (Lowry *et al.* 2013). In this study, we also recorded that jackal pups were being fed anthropogenic food regurgitated by the breeding pair and helpers, suggesting that even the pups are being reared through human provisioning. Traits like these may be game changers in the urban context for species to gain access to critical resources that can enhance not just their survivability but also that of their offspring.

On the notion of "wild" in the urban context, we observe that, while domesticated species are integral to daily city life and their presence is not just tolerated but also encouraged by human beings, the presence of wild animals in the city is often unacknowledged, especially because their cryptic biology and behavioural adaptations render them invisible. A 1999 publication by the Delhi government features maps that label large swathes of the Ridge forest as a wasteland, completely overlooking their ecological functions (Crowley 2015). Such a view has been instrumental in the "parkification" of the Ridge forest—systematic intervention by the management has led to the conversion of native vegetation patches into manicured and aesthetically pleasing recreational spaces (Baviskar 2018). Nature in the city is being reimagined to conform with ideas of order, beauty, and safety. In other words, "natural" has to be managed within an acceptable range, a point made clear in the Delhi Master Plan's categorization of land use as "green areas" but with an emphasis on not allowing these areas to take the form of unmanaged wilderness (Baviskar 2020). By deeming natural spaces in the city as "wild", "wasteland", "degraded", "invaded", or in need of "development", urban planners overlook the many nonhuman creatures that occupy these habitats, thus increasing their precarity (Palmer 2003).

Still, conservation biologists continue to view urban wildlife as 'threatened' by shrinking habitats and local extinction (Magle *et al.* 2010). The Ridge is now a Reserved Forest, and this title offers a layer of protection to the area. There is also ongoing work by the forest department to eradicate the invasive *Prosopis juliflora* vegetation and restore native forests. As these forest patches have been increasingly brought under strict protection, the fate of the fauna becomes uncertain. As noted in this study, the wild urban fauna are adapters that have attuned to human provisioning for sustenance. With tall walls and fences around the forest for protection, their mobility and ability to access resources from neighbourhoods are becoming increasingly difficult. There are obvious challenges in the development of effective conservation strategies in these novel ecosystems, primarily because conventional conservation biology is unfamiliar with the urban landscape (Parker 2015).

The idea that "disturbed" urban ecosystems can nevertheless support wildlife populations is noteworthy because it opens up possibilities for research on how these populations survive in such ecosystems. Our study indicates a need for alternate frameworks to describe habitats that are wild and urban, and composed of novel plant associations (Chauhan *et al.* 2022). There is a growing trend in historical ecology to break the discourse around the pristine idea of nature and view urban habitats not as isolated natural habitats but as socio-ecological landscapes embedded in burgeoning metropolises (McDonnell 2011; Cavin and Kull 2017).

Is it necessary to view urban wilderness and wildlife as dwindling, degraded, and in urgent need of conservation focus? Are there alternative frameworks that visualize these landscapes as coevolutionary and adaptive frontiers, where species are not perceived as victims but as successful urban adapters? Jamie Lorimer (2015) expresses dissatisfaction with a cross-section of studies on wildlife across urban landscapes using present-day urban conservation paradigms and emphasizes the need for "anticipatory semantics". He espouses "cosmopolitics for wildlife" and highlights the need for "new forms of interspecies responsibility" (pp. 179).

While this study provides insight into the pressing concerns surrounding the persistence of urban wildlife, the debate is far from settled. Frameworks based on pure conservation, especially with the establishment of protected area systems, may not be appropriate for such landscapes. Instead, these urban spaces need to be seen as adaptive margins of the conservation realm, where species have coevolved and adapted to the unique conditions and resources that these urban habitats provide. As our study indicates, the species that presently inhabit the Ridge have lived through several changes over the years—they have survived, responded, and adapted to these changes. This study accentuates the need to seriously rethink urban nature in general and urban planning and to incorporate critical insights and explore alternate frameworks that liberate us from the tyranny of green constructs. As Schilthuizen (2018) and Lorimer (2015) propose, urban wildlife habitats can be reimagined with porosity and some inviolate pockets, allowing for further adaptation, with as large a reservoir of genetic diversity as possible. With present rates of urbanization—both in terms of the number of cities and geographical extent—such a rethinking is crucial.

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Data Availability statement: The data used to support this research is available in a repository and the hyperlinks and persistent identifiers (e.g. DOI or accession number) are stated in the paper.

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