Urban Commensalism & Aviation Safety

PAWS Web
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A Dynamic Approach to Birdstrike Mitigation

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<u>**Submitted by:**</u>

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This study was undertaken as a pilot research initiative in furtherance of Thinkpaws' charitable objects. The findings are shared in public interest to advance knowledge on urban–defence–ecological coexistence.

Executive Summary

In human-dominated landscapes, anthropogenic activities often impact biodiversity. However, certain resilient species, particularly avian taxa with volant habits, exhibit a notable capacity to thrive in these environments. They adeptly evade direct human interactions, capitalising on the abundant resources available, chiefly in the form of habitat and food. Several bird species have capitalised on anthropogenic food subsidies, facilitated by practices such as ritual feeding and the presence of garbage. Among these urban exploiter bird taxa, facultative scavengers have been implicated in birdstrikes worldwide due to the spatial proximity of airfields to large landfills and other garbage sources. The infrastructural homogeneity observed in urban areas, often characterised by a core-to-periphery design, further accentuates the prevalence of these scavengers. As garbage disposal becomes more rationalised, human refuse has transformed into a highly predictable, albeit low-quality, food subsidy. These dynamics underscore the complex interplay between human activities and wildlife in shaping urban ecosystems that are prone to birdstrikes.

Agra aerospace located approximately 500 km south-east from the Trans-Himalayan range—an ecological barrier and conduit for millions of wintering birds in the region— represents a contested space shared between birds and aircraft due to its geospatial location. The reconnaissance survey at Agra (and Agra AFS) that lasted from 3rd - 6th November and 16th - 17th December in the year 2023 aimed to explore the ecology of birdstrike threat posed by Black kites *Milvus migrans* that are facultative scavengers, arguably the most common birds of prey in the world.

If we link the history of the spatial dispersion of garbage-based food subsidies as a function of the urban history of human settlement in the city of Agra, we should arrive at the understanding that waste and landfills have been recently appreciated for their influence on life and physical features like biodiversity and climate change, by creating new Anthropo-stratigraphic and geological layers. Therefore, any attempt to ensure convivial aerospace for birds and machines should cater to an ecological understanding about historical and concurrent ecological drivers of congregations that pose birdstrike threat. Habitat configurations that stem from linkages in the urban ecosystem should also be a matter of interest and research conducted to become more informed about the dynamics of these interactions.

The historical aspects of Agra, as explored in this study, has played a significant role in the behaviour and interaction of Black Kites with the urban environment. The city of Agra has undergone a rapid urbanisation process that has altered the spatial distribution of garbage (and created landfills), which provide food subsidies for many opportunistic species of birds, such as kites, crows, and pigeons. Rapid and predictable increase in abundance and distribution of such opportunistic birds in urban areas pose a serious threat to the safety of aircraft operations. Garbage and landfills also have ecological and environmental impacts, such as creating new anthropogenic layers in the soil, affecting the local climate, and restricting/altering the natural habitats of other species.

Therefore, to prevent or mitigate the risk of bird strikes, we deemed it essential to understand the historical and current ecological drivers of kite congregations in urban areas, as well as the habitat configurations that facilitate or hinder their movements and interactions. The pilot survey informed that it requires a comprehensive and interdisciplinary research approach that integrates data from different sources, such as remote sensing, field/social surveys, and birdstrike reports. By doing so, we can develop effective strategies and policies to manage the urban ecology of opportunistic species and ensure a harmonious coexistence between birds and machines.

In our preliminary study, we employed Integrated Surveillance Technologies approach to monitor the behaviour and movement of Black Kites. This comprehensive approach combines three key methods:

1. **Ocular Monitoring**: This real-time assessment method, with a spatial range of 50-100m radius, allowed for high-resolution monitoring of kite activities like flock formation, mating rituals, and foraging on wings. It also helps in monitoring the impacts of spatial- temporal changes in infrastructure, food subsidies, and socio-cultural practices and beliefs on kite behaviour.
2. **Testing UAV Surveillance**
3. **Exploring the potential opportunities for GPS-Tagging Black Kites**: This remote assessment method covers several kilometres and links real-time monitoring with kite movement and behaviour through camera trap-based 24/7 surveillance.

By integrating these technologies, we suggest gathering comprehensive data that can be analysed using artificial intelligence and machine learning for effective bird strike mitigation. This approach underscores the importance of leveraging advanced technologies in wildlife management and conservation efforts, particularly in urban ecosystems prone to birdstrikes. It also highlights the potential of these technologies in developing effective strategies for human-wildlife coexistence in urban landscapes. The potential study at Agra to mitigate birdstrike will greatly benefit from these insights and methodologies.

Background

Land-use and human population changes have been studied to impact wildlife within and outside cities (Anonymous, 2016), but there is poor information on how they affect the use of aerospace by birds. By 2033, worldwide urbanisation and concentration of wealth would double the number of 'aviation mega-cities' to 91, leading to ~5% annual growth in air-passenger traffic over the next

20 years (Airbus, 2014). This higher air-traffic, in addition to the anticipated use of manned/unmanned drones for freight and other purposes, pits birds and aircraft against each other in limited aerospace. According to the annual estimates by the Indian Air Force (IAF), bird strikes annually affect ~1500 military and civilian aircraft in the region. Further, birdstrike damage costs several crores per unit in repairs, not to mention the occasional loss of aircraft and precious human lives in crashes (*pers comms.* IAF).

Amongst various bird species in South Asia, avian scavengers- primarily Black kites *Milvus migrans*-feature most prominently in birdstrike-hazards that damage aircraft (>62% cases; *pers comms*. IAF). Black kites are the most numerous and successful birds of prey of the world (Ferguson-Lees & Christie, 2001). Delhi - where kites have been continuously monitored for more than a decade - has a population of about ~60,000 resident breeding (*M. m. govinda*), and an unestimated large population of hundreds and thousands of non-breeding kites from the resident and migratory race (*M. m. lineatus*) that gather in spectacular concentrations at abattoirs and open garbage/landfill sites (Kumar et al., 2014, 2018; Kumar, Singh, et al., 2019; Kumar et al., 2020). Landfills and/or open garbage dumps are often in proximity of airbases/airports in the Delhi and Near Capital Region (NCR). Preliminary research, based on GPS-tracked resident and migratory kites has shown that ecological responses of kites to garbage-piles/landfills (often in the city outskirts) pose significant birdstrike threats at nearby airfields/ceremonial flight paths, like the one used during the Republic Day Parade in India (see Kumar et al., 2018, 2020).

Apart from soaring raptors, bats, nilgai, monkeys (Rhesus macaques and Hanuman langurs), jackals, dogs and small birds like lapwings, starlings, swifts, swallows, etc. occasionally cause damage to the aircraft (pers comms. IAF). Collectively, these pose a threat to national security and civil aviation. Based on the prior experience of working in Delhi, People, Animals, and Waste Systems' Web (PAWS-Web) can provide ecologically informed solutions to bird strike hazard, by incorporating studies on population ecology and behaviour, and by using the latest GSM-GPS telemetry devices and Artificial Intelligence that combines the telemetry and geospatial data with real-time inputs from bird-radars (as and when they become available) (Kumar et al., 2020). Alongside, we aim to explore if planned waste-management can govern the availability and accessibility of food-subsidies for kites and other conflict species to reduce aforementioned threats (Kumar et al. 2019c).

Species of concern: Black Kite (Milvus migrans)

The Black Kite (*Milvus migrans*) is a medium-sized raptor that is currently considered to be one of the most numerous and successful birds of prey in the world (Ferguson-Lees & Christie, 2001). A generalist, opportunistic feeder, it is capable of reaching extremely high densities where food concentrations allow it (see, for example (Desai & Malhotra, 1979; Ferguson-Lees & Christie, 2001; Kumar et al., 2014). It may occupy habitats ranging from fully natural to completely urban. This opportunism and capability to exploit human-modified habitats has afforded the species a generally favourable conservation status, with frequent reports of recently increasing populations, despite some local declines (Kumar et al., 2014).

The ability of kites to adapt to human environments is most evident in populations that nest in urban areas, as is often seen in Asia and Africa (Desai & Malhotra, 1979; Ferguson-Lees & Christie, 2001; Naoroji, 2006). These old-world kites form spectacular concentrations of wintering birds (*M. m. lineatus*) on landfills (Kumar et al., 2020). In these settings, kites use the urban ecosystem for nesting and for feeding on human waste, roadkill, animal carcasses, and garbage. They are often found hovering in small to large flocks, over open spaces or at garbage dumps in large cities. When these dumps are located near airports, or military airstrips, the concentration of kites can create serious management problems due to the risk of collisions with aircraft (Kumar et al., 2014). This capability to adapt to human landscapes reaches its extreme in populations that nest or winter in fully urban conditions, as frequently observed in Asia and Africa.

Quite remarkably, despite their overall abundance and frequent proximity to humans, the migration routes and breeding areas of the massive populations of Black-eared kites wintering in and around the National Capital Region landscape in India - which hosts the largest raptor concentration of the world - were unknown. Kumar et al., (2020) have recently explored their migration route, which is a 3,300–4,800 km long flight path along a narrow corridor. Black-eared kites crossed the Himalayas at extremely high elevations (up to > 6500 m a.s.l.) by the mount K2 of the Karakoram Range and travelled long periods at elevations above 3500 m. On their return journey, once the birds were across Himalayas, kites then crossed/circumvented the *Taklamakan* Desert and *Tian Shan* Range to reach their unknown breeding quarters at the intersection between Kazakhstan, Russia, China, and Mongolia.

Given the limited research on the migratory routes of wintering Black-eared kites, it is crucial to investigate the potential network of cities within the National Capital Region (NCR) that these populations might be utilising. Specifically, the city of Agra warrants particular attention due to its potential role within this network. The study conducted by Kumar et al., (2020) provides compelling evidence that kites utilise a network of cities that lie within a 100 km radius from Agra. This finding suggests the possibility of interconnected subpopulations of wintering kites across Agra and other cities within the NCR. These subpopulations potentially rely on a network of human refuse across these urban areas, which could have significant implications for their survival and migration patterns (Newton, 2010).In ecology, the term migratory connectivity refers to the study of spatio-temporal linkages between native and wintering populations. Migratory connectivity not only impacts the survival of individuals and populations, but also the spread of pathogens and diseases (Newton, 2010). Therefore, it is imperative to conduct a comprehensive study of the kite population in Agra in conjunction with the population of migratory kites in Delhi and other cities within the NCR, such as Aligarh and Mathura.

This study aims to elucidate the interdependencies and interactions among Black Kite subpopulations in relation to regional urbanisation across multiple cities. The insights we gain shall enhance our understanding of their ecology and behaviour. Tailored strategies addressing the unique challenges posed by the two subspecies could alleviate birdstrike concerns for the Indian Air Force. Comprehending the movement and behaviour of wintering kites across Agra and the National Capital Region (NCR) is crucial for developing effective bird management measures and

mitigating birdstrike threats, thereby ensuring coexistence in aerospace. Black kites, use of Agra's aerospace is shaped by three historical factors: the prevalence of litter in streets, the city's predictable infrastructure due to its historical status as a fort-city, and the cultural disposition of people towards kites. These elements influence the kite's behaviour, leading them to frequent areas near humans and infrastructure, posing a potential risk to aircraft.

Agra: how does a historical city with conspicuous architecture promote commensalism?

Agra, a city renowned for its architectural marvels is also home to a rich ecological tapestry owing to a dynamic history of land use changes. For centuries, avian and non-avian commensals have been part of the city's landscape. While commensals associated with livestock rearing practices by the urban poor have been documented, kites have not been reported in pre-Mughal texts (Viswanath, 2014). The Mughal period from 1526 to 1805 AD was significant for its characteristic impacts on infrastructure in the form of buildings such as the Taj Mahal, Agra's Red Fort, and the nearby city of Fatehpur Sikri. Reportedly, about 5,000 buildings were present around the complex of the Red Fort. This mediaeval era settlement, with an average area of 760 m2 per building, had a housing density comparable to modern cities. The Mughals also built over 44 garden complexes throughout Agra, including the garden bands along the river Yamuna, on either side. A few of these gardens still survive, providing a glimpse into the historical urban context of the city (Viswanath, 2014; Fig. 1 and 2).

The dietary culture of Agra changed during the Mughal era, shifting from a predominantly vegetarian diet to one that included more meat. This likely provided foraging opportunities for numerous commensals, including kites. The presence of garden complexes associated with urban infrastructure ensured two vital resources for kites, food and nesting habitat, in close proximity (Kumar, Gupta, et al., 2019; Newton, 1979). This spatial history of agriculture feeds into the ecological characteristics, where regional socio-cultural choices mediate commensal ecology and behaviour.

Through these transitions, various aspects of cattle farming and animal husbandry, such as breeds, products, health, management, and environmental impacts, were influenced by spatial correlation in shared spaces used by people involved in production and use of animal products, leather items, and artisans. This correlation is due to the geographic proximity and similarity of activities or preferences. For example, people who use animal products or leather items are more likely to have lived near cattle farms or slaughterhouses, where they could access the raw materials for their livelihoods or consumption (Farquhar, 1920). Similarly, artisans who made crafts or products from animal parts clustered in certain areas where they could sell their goods or exchange skills. Opportunistic scavengers, such as urban raptors, have likely taken advantage of the waste or carcasses generated by cattle farming or animal processing, and have been historically more abundant or diverse in those areas (Naoroji, 2006). These spatial patterns in tropical cities such as Agra have had implications for the ecology, economy, and culture of the regions where cattle farming and animal husbandry are practised (Kumar, Singh, et al., 2019).

The arrival of the British in India (1803-1947 AD) further strengthened the centralised aspects of animal husbandry practices. They developed the peripheral areas of the city and revitalised large sections of the Mughal urban area (Farquhar, 1920). The introduction of modern amenities, including railway stations, factories, golf courses, and race grounds, were major additions during this time (Roy, 1999). Other important developments during this period included public parks and roads connecting major buildings. Dietary habits in colonial times led to the opening of slaughterhouses in many parts of the country. In the colonial era, Agra had approximately nine slaughterhouses until 1956. This period also saw Agra emerge as one of the most important centres for leather tanning, collection, and supply of hides and skins. For these factories, they recruited lower-caste people and Muslims, as they were readily available for this work (Kain, 2018).

Since the British settlements were established in previously developed areas, the spatial differences in infrastructure that provided cues to avian scavengers likely became more pronounced, especially in the case of semi-colonial raptors, such as kites that engage in social foraging and have long lifespans (Ferguson-Lees & Christie, 2001; Naoroji, 2006; Newton, 1979). After independence, the city witnessed a large influx of refugees and migrants from rural areas, which resulted in the congestion of the central part of the city. To promote industrial development,

three major industrial areas were established in the 1970s to 1980s: Nunhai, Sikandra and Foundry Nagar (Roy, 1999). These developments stimulated the expansion of the city in the north-western and north-eastern directions, of which the north-western section holds vital importance, considering the arrival of wintering kite populations (Kumar et al., 2020). Between 1991 and 2021, the urban built-up area of Agra Municipal Corporation increased by more than 170%, from

27.19 km2 to 74.64 km2. The city also has a significant reserve forest area of 1912.20 ha, and 58 parks, including three city-level parks: Shahjahan Park, Paliwal Park and Nehru Park (Fig. 1 and 2) (Roy, 1999).

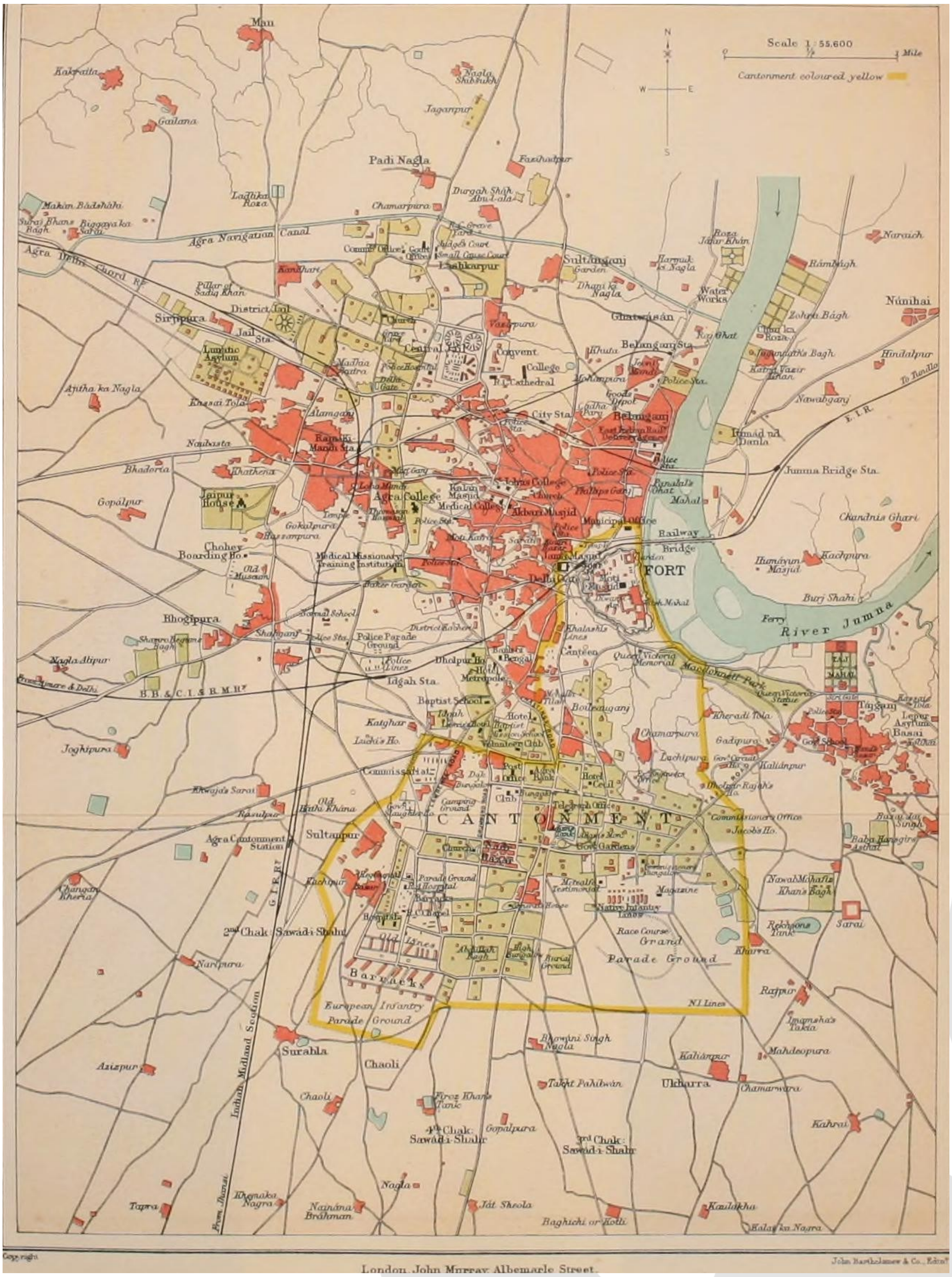

Fig. 1. Pre-independence era map of Agra. (Source: Wikimedia Commons)

With regard to contemporary developments, the leather industry, which was a primary source of income for many Muslims and Dalits, has faced a number of challenges since partition and the recent government crackdown on illegal facilities (Kain, 2018). These socio-political events and gentrification drives have likely altered the ecological and cultural geography of the city in ways that are not well understood. Agra is also home to one of Uttar Pradesh's four government-run slaughterhouses and is a major hub for the state's meat export industry, which accounts for nearly half of India's total meat exports. The history of Agra reveals how the city's infrastructure and cultural and political history are intertwined and shaped by various factors, such as migration, industrialisation, environmental conservation, and religious diversity(Kain, 2018; Roy, 1999). The city's urban ecology reflects the complex and dynamic interactions between human and natural systems, and the opportunities and challenges that arise from them. Therefore, cities like Agra and Delhi with their spatial history of agriculture feed into the ecological characteristics of the landscape, where regional socio-cultural choices mediate commensal ecology and behaviour (Kumar, Singh, et al., 2019).

Aim:

A reconnaissance survey to explore the habits and habitats of Black kites in the city of Agra, in relation to the birdstrike issues.

Objective:

1. To investigate the variety of behaviours and habitats of kites in the city of Agra.
2. To examine how the geographical location of the city of Agra and its infrastructural history have created suitable habitats for resident and migratory populations of kites.

Methodology:

Habitat Assessment

To understand the spatial distribution and abundance of Black kites in Agra's urban ecosystem, we implemented a stratified habitat assessment approach (see Kumar et al., 2014; Kumar, Gupta, et al., 2019). Before choosing random locations for monitoring (Table 1), we initially divided the city into distinct strata based on key variables influencing kite ecology, such as:

3. **Land use:** This included broad categories like residential areas, commercial zones, industrial zones, green spaces, and open water bodies. Each category was further subdivided based on specific characteristics like building density, vegetation cover, and presence of human activity (socio-cultural and religious aspects).
4. **Garbage availability:** We mapped the spatial distribution of garbage dumps, landfills, and other potential food sources for kites within each land use category. We classified these garbage sources based on size, accessibility, and frequency of waste disposal.
5. **Proximity to the vital areas of concern:** The study area was further stratified into concentric zones around the AFS, considering the potential influence of aircraft activity on kite movements. The aim of our study was to understand habitat preferences of the wintering and resident breeding populations, given that breeding home ranges of kites are <2 km; we have no information on the wintering birds' range/the non-breeding range of the govinda birds (Kumar et al., 2018).

These habitat stratifications would be useful for planning a potential study on the breeding ecology of kites in the city (see Kumar et al., 2014). Within each stratum, we employed a combination of field observations (using binoculars and range finders) and remote sensing techniques to gather detailed habitat data. Field surveys involved recording kite sightings, behaviour, and interactions with the environment at predetermined points or along transects (using vehicles for road transects). We also collected data on habitat features like vegetation type, canopy cover, ground cover, and presence of artificial structures. Remote sensing imagery (e.g. satellite and aerial photographs) was used to map land use patterns, identify potential nesting sites, and analyse changes in garbage availability over time. This stratified approach allowed us to compare and contrast habitat features across different urban landscapes and assess their potential influence on kite distribution and foraging behaviour. By linking habitat data with bird observations and strike records, we aimed to identify key habitat components that contribute to the birdstrike threat near the AFS and inform targeted mitigation strategies (e.g. waste management; see Fig. 2 and 4). Collectively, we sampled more than 30 locations for kite activity and behaviour.

Assessment of food subsidies for kites in Agra

To understand the role of anthropogenic food subsidies in supporting migratory and resident kite populations in Agra, we employed a multi-pronged approach:

1. Mapping and Characterisation of Food Sources:

We conducted a comprehensive survey of Agra's urban landscape to identify and map all potential sources of food subsidies for kites, including:

- **Garbage dumps and landfills:** We documented the location, size, type of waste, and frequency of waste disposal at these sites.
- **Open waste dumps:** We identified smaller, open waste dumping grounds often found near settlements and markets.
- **Sewage treatment plants:** These can attract kites due to the presence of organic matter and insects.

- **Slaughterhouses and meat processing units:** These can provide kites with carrion and scraps.
- **Street food stalls and markets:** Food waste from these establishments can be readily scavenged by kites.

2. Quantification of Food Availability:

At each food source identified, timed observations were conducted to estimate the number and sub-species of birds (resident/migratory kites) utilising the resource. We supplemented these observations with drone imagery and video recordings to capture a wider spatial and temporal perspective of bird activity at these sites. We also cursorily analysed waste management data from Agra Municipal Corporation and slaughterhouses (both private and federal) to assess the quantity and composition of waste generated in different parts of the city.

3. Meat Tossing Experiment:

To assess the adaptability of Agra's kites to exploiting novel food sources, we conducted a controlled experiment in select locations (Table 1). We tossed pieces of meat at specific times and recorded the number of kites attracted and their response to the food offering. This experiment helped us compare the scavenging behaviour of Agra's kites with those observed in other cities where meat tossing is a more common practice (Kumar et al., 2018; Kumar, Gupta, et al., 2019).

Behavioural assay to study human-kite mutualism

To gauge the habituation of Black kites in Agra to human food subsidies and their potential impact on habitat suitability near the AFS, we conducted a unique behavioural assessment exploring the concept of human-kite mutualism. This assessment hinged on the meat tossing experiment mentioned earlier. By analysing the kites' response to mid-air food offerings at different locations, we aimed to understand the interplay between their inherent neophobia (fear of novelty) and the potential neophilia (attraction to novelty) towards anthropogenic resources.

The variation in response across different city sections shed light on the geographical influence on this trade-off. Areas with limited street garbage, where kites were observed not responding to meat tossed in the air, indicated a lower level of habituation to human-provided food. Conversely, locations with readily available street food or waste dumps might trigger a stronger neophillic response, encouraging kites to exploit these unconventional food sources. By correlating habituation patterns with habitat features and proximity to the AFS, we aimed to assess the suitability of different urban landscapes for kite breeding and other activities. For instance, areas where kites readily accepted mid-air food, potentially indicating a higher degree of neophilia and reliance on anthropogenic resources, might also be more prone to birdstrike threats near the AFS due to increased foraging activity in the vicinity. This behavioural assessment, therefore, served as a bridge between understanding the individual-level response of kites to human food subsidies and extrapolating it to assess habitat suitability and potential birdstrike risks at a landscape scale. By uncovering the complex interplay between neophobia and neophilia, we sought to provide valuable insights into managing human-kite interactions and mitigating birdstrike threats around the AFS.

By combining these methods, we aimed to gain a comprehensive understanding of the food subsidy landscape in Agra and its role in supporting Black Kite populations. This information is crucial for predicting potential birdstrike risks associated with different food sources and informing targeted management strategies to reduce bird-aircraft interactions around AFS Agra.

Results

Our study identified two subspecies of Black kites in Agra - the Resident Govinda and the Migratory Black-eared kite Milvus migrans lineatus. The resident kite, with a wingspan of approximately 120 cm and weight around 700 g, and the migratory kites, with a wingspan of approximately 160 cm and weight around 1200 g, were found to utilise different resources within the urban environment (data from: Ferguson-Lees & Christie, 2001). The breeding status of these kites further diversified their habits. Breeding birds are known to base their habitat selection on past experiences for purposes like foraging and mating rituals. Thus, airfield-based birds were mostly adults performing mating rituals. Given that the overall concrete area is negligible in comparison to the city, in terms of eliciting a microclimatic effect, these observations on mating rituals within flocks also negated the misconception about kites using AFS to benefit from air thermal effects (Fig. 6). Non-breeding birds exhibited a predictable pattern for foraging - linked with the refuse sites - but did not show high plasticity in terms of habitat and food choice.

In terms of habitat selection, both subspecies most likely based their wintering and roosting/nesting habitat preferences on past experiences, primarily for roosting and foraging. However, their foraging abilities varied. Resident kites demonstrated a good ability to find short- term food sources influenced by social behaviour and familiarity with built environments. In contrast, migratory kites exhibited a reduced capacity to locate short-term food sources, which was further influenced by other internal and external factors (see Sumasgutner et al., 2021 for details). The latter relied on more predictable resources associated with landscape features, such as landfills, that afforded access to human food subsidies without the requirement of proximity to people (Table 1;

Fig. 3).

Fig. 3. Black Kite Birdstrike Threat: A Comprehensive Overview of Subtypes, Breeding Status, Habitat Selection, Foraging Abilities, and Potential Solutions.

Date	Place	Activity	Observations
3.11.23 to 6.11.23; 16.12.23	Agra Cantt Area and the adjoining city complex	Flocks of resident kites in mating rituals	The activity grew in intensity in the month of December
in 4.11.23. 17.12.23	Kuberpur landfill Kuberpur Reserve Forest [*no attraction to meat tossing*]	Small flocks of kites, comparable to those at the Bhalswa and Okhla landfills of Delhi, with an unusually high number of Egyptian vultures.	**~400-500 birds in November** (50% resident breeders, 30% Egyptian vultures, and 20% *lineatus* birds) **~800-1000 birds in December** (75% *lineatus* birds, 20% Egyptian vultures, and 5% resident breeding kites)
4.11.23 16.12.23	Red Fort Complex [*no attraction to meat tossing*]	Monitoring of flocks	Flocks primarily comprised of resident spp., which were in mating ritual displays.
4.11.23 5.11.23 17.12.23	**Cheel Ghar Chauraha** (small scale regional dumping of waste, which is associated with a lot of constant present of kites) [*kites attracted to meat tossing*]	Flocks of kites, (n = 20 to 100, based on the time of the day)	kites from the resident spp responded to meat tossing, albeit, they were not as adept at picking the meat chunks mid-air, like the kites in Delhi. The numbers quickly rose from <20 to >150, in response to meat tossing.
4.11.23 5.11.23 17.12.23	Idgah Complex [*no attraction to meat tossing*]	Very few birds in sight	Despite the history of meat tossing in the recent past, kites did not respond to meat tossing.
5.11.23 17.12.23	Shah Jahan Garden Paliwal Park Subhash Park Moksha Dham	Monitoring of flocks, and trees for nests	While we did not find any nest in November, we sighted >20 nests during our road transects in December
5.11.23 17.12.23	Shah Ganj	Monitoring of flocks	Small flocks of resident birds (n = <30)
5.11.23 17.12.23	ISBT Babarpur Area Dayal Bagh Yamuna Bank Yamuna Bank (Dayal Bagh)	Monitoring of flocks	The number of active nests increased from one to >10 during November to December (near ISBT). Unlike Delhi, the Yamuna Bank area did not have flocks of kites bathing in the water.
4.11.23 to 6.11.23; 17.12.23	Radisson Hotel Area St. John's College Jama Masjid Sadar Baazar	Monitoring of flocks	Small flocks of resident birds (n = <30), except the case of Jama Masjid, where the numbers went beyond 100.
6.11.23 17.12.23	Taj Mahal Area Taj Protected Forest	Monitoring of flocks	A few resident breeders in flight
17.12.23	Sevla Area	Monitoring of flocks	A few resident breeders in flight

Table 1. Summary of Black Kite Monitoring Activities in Agra, detailing dates, locations, activities, and observations

Habitat Assessment

The habitat diversity for kites in Agra reflects the city's historical, cultural, and socio-economic facets (Fig. 7). Understanding this diversity is crucial for developing effective strategies for human-wildlife coexistence in urban landscapes. This aligns with the findings from our research on Black kites in Delhi, underscoring the importance of urban ecology in understanding and managing wildlife in rapidly urbanising cities. Based on a survey conducted between November and December 2023, the city of Agra presents a diverse habitat for Black kites. The city's rich history, coupled with its urban development and cultural practices, has created a unique ecological niche for these birds (Table 1).

The city's infrastructure, shaped by its historical status as a fort-city and the subsequent industrial development, provides ample foraging and nesting opportunities for Black kites. The presence of garden complexes associated with urban infrastructure ensures that two vital resources for kites, food, and nesting habitat, are in close proximity. The AFS Agra, which has been in existence for over 100 years, adds another dimension to the habitat diversity, in terms of birds that are neophobic and live beyond 20 years (Fig. 7). While their presence at AFS poses challenges to kites due to the risk of birdstrike mitigation measures, it also represents a significant landmark that could potentially impact the spatial preferences of these birds (Fig. 6). Furthermore, the city's waste disposal system and the cultural disposition of people towards kites also influenced the behaviour of Black kites. The city's solid waste disposal system provides chances for a comprehensive study on the connections between food resources and the behaviour of kites for a long-term assessment.

Food Subsidies

In relative terms, streets in Agra were relatively cleaner than Delhi, which should be the limiting factor for the overall breeding density of kites. Furthermore, Agra's only major landfill (Kuberpur) is significantly smaller than the landfills of metropolitan cities in the country, measuring approximately one-third the size. Given that the fish and chicken markets are not connected to this landfill, the size of the kite flocks (see Table 1) is comparable to those in Bhalswa and Okhla in Delhi (n = <1000 during the peak season, December - February), underscoring the significance of these meat processing units and their distribution throughout the city. In contrast, the Ghazipur landfill, which houses Asia's largest poultry and egg market, has been home to an estimated 10,000 kites, mostly of the migratory variety (Kumar et al., 2020).

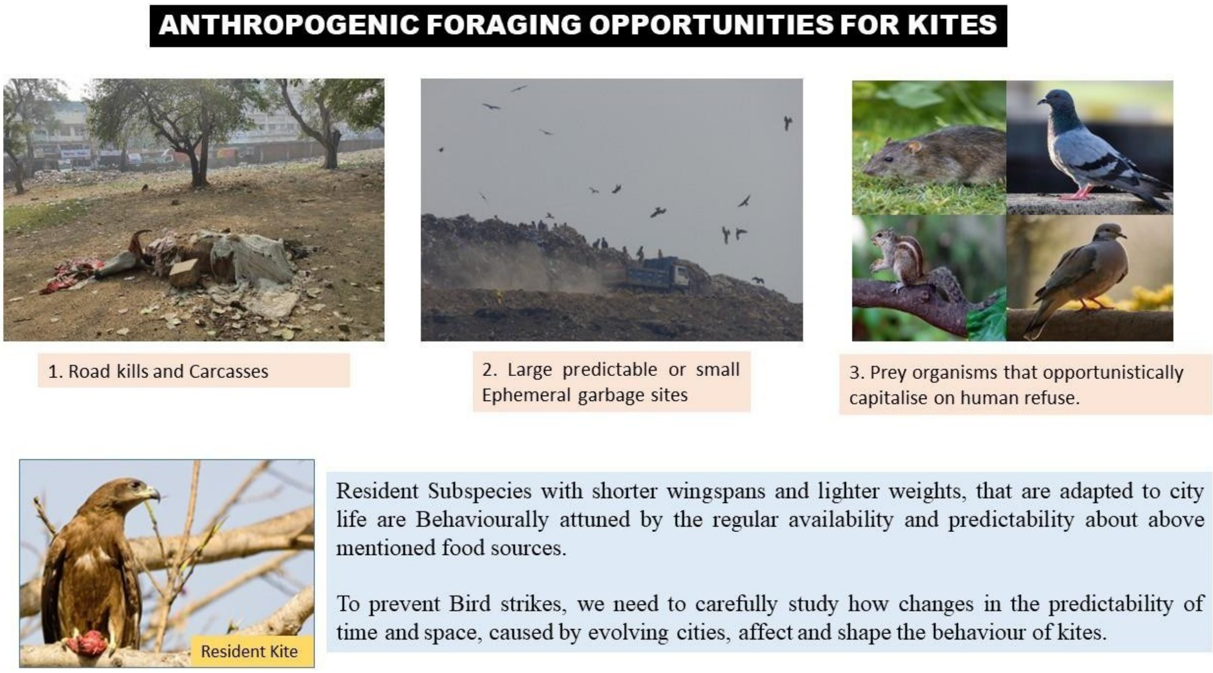

Fig. 5: Black Kite Birdstrike Threat: an overview of subspecies, breeding status, habitat selection, foraging abilities, and mitigation strategies.

Human - Kite Mutualism

In total, meat tossing was carried out at four locations: Kuberpur, Idgah, Agra Fort, Cheel Ghar. Considering the fact that we targeted this meat tossing to understand human-kite mutualism over scavenging services that take the form of ritual feeding, it was unexpected to find kites attracted to the regional garbage disposal unit near the Agra Red Fort. Even within the flock of kites that gathered in response to meat tossing, we noted that the birds were not adept at foraging on wings, while off-taking meat chunks (see images in the Appendix). Specific instances that we noted:

- **Integrated Surveillance**: Implementing an integrated surveillance system that combines radar, visual observation, and habitat analysis is crucial for identifying areas of high kite activity and understanding seasonal and spatial variations in their movements. This information can then guide targeted mitigation measures to specific zones and periods, minimising impact on overall kite populations (see Discussion).

- **Cost-effective and planned deterrence**

Discussion

Our research in Agra revealed the limitations of simplistic, one-size-fits-all approaches to Black Kite management in rapidly urbanising environments. Embracing the heterogeneity of urban landscapes and the multifaceted behavioural adaptations of individual kites is key to designing effective, sustainable coexistence strategies.

Heterogeneity and its Ecological Imperative: Agra's patchwork of dense settlements, sprawling suburbs, and green spaces creates a mosaic of habitat suitability for kites. Densely populated areas with limited garbage availability may trigger neophobia, discouraging foraging activity. Conversely, suburbs with open waste dumps and green spaces potentially encourage neophilia, attracting and sustaining large flocks (Anderies et al., 2007; Hale et al., 2015; Kumar, 2023; Kumar, Gupta, et al., 2019). Recognizing this spatial heterogeneity is crucial for targeted interventions, ensuring resource efficiency and maximising impact.

- **Behavioural Plasticity as a Survival Strategy:** Our observations suggest Black kites exhibit remarkable behavioural plasticity in response to urban pressures. Their neophobia- neophilia trade-off, influenced by food availability and habitat structure, is a dynamic response to rapid environmental changes. Recognising and quantifying the spatiotemporal shifts in this trade-off will allow us to:
- ***Predict future behaviour patterns*:** By charting how kites adapt and shift their activity in response to urban development, we can anticipate future areas of potential birdstrike risk, thereby allocating resources proactively.
- ***Refine mitigation strategies*:** Understanding the triggers and thresholds of neophobia and neophilia allows us to tailor deterrent or diversionary measures to specific locations and seasons, maximising effectiveness while minimising undesirable impacts on kite populations.
- ***Develop context-specific interventions***: Recognizing the distinct behavioural strategies employed by resident and migratory Kite subpopulations is critical for targeted management. For instance, exploiting the aversion of resident kites to novel food sources through strategic habitat modification might prove more effective than deterrence techniques suitable for

migratory populations.

Embracing Long-Term Monitoring and Adaptive Management: A cornerstone of effective Kite management in Agra is a robust long-term monitoring program. Continuous data collection will enable us to:

- ***Track spatio-temporal population dynamics*****:** Monitoring population size, distribution, and breeding success across Agra's diverse urban landscapes will provide crucial insights into the long-term impacts of urban development and inform adaptive management decisions.
- ***Evaluate mitigation effectiveness***: Long-term monitoring allows us to track the efficacy of implemented strategies like food diversion, habitat manipulation, and deterrents. This data-driven approach ensures that resources are directed towards interventions with demonstrably positive outcomes.
- ***Foster adaptive management*****:** Implementing a flexible and iterative approach to Kite management is crucial, considering the constant interplay between urban development and avian adaptation. Continuous data collection and analysis will empower us to refine and adapt our strategies over time, ensuring their long-term efficacy.

Coexistence in the Urban Mosaic: Our study highlights that managing Black kites in Agra, and in any urbanising city, requires acknowledging the complexities of ecological systems. By embracing heterogeneity, studying behavioural plasticity, and implementing long-term monitoring, we can move towards a future where human progress and avian conservation coexist in harmony. This shift in perspective, from static solutions to dynamic management, offers the promising potential for a safer and more sustainable future for both humans and kites in our ever-evolving urban landscapes.

Fig. 6. Predictable Congregation of Black kites at AFS Agra: influenced by foraging opportunities that links with mating rituals and anthropogenic factors.

Bridging the Gap: Integrated Technologies for Birdstrike Mitigation in Agra

Kites' soaring presence above Agra AFS poses a significant threat to aviation safety. These birds are attracted to the station's open fields and abundant food sources, such as rodents, birds, and insects (Fig. 6). They often fly close to aircraft, which can pose a hazard to pilots and the aircraft engine. Our proposed Integrated Surveillance Technologies (IST) offer a promising roadmap for tackling this challenge (Fig. 8). IST is a multi-faceted approach that combines diverse monitoring methods to gain a comprehensive understanding of the kites' behaviour. These methods include:

- **Ocular Monitoring:** Ocular monitoring is a method of observing kites using telescopes or binoculars. This method provides detailed information about flock dynamics, foraging patterns, and responses to environmental changes. Ocular monitoring can be used to identify areas where black kites are most likely to congregate, which can help to reduce the risk of collisions with aircraft.

- **UAV Surveillance**
- **GPS-Tagged Black Kite Remote Assessment (in association with trail cameras on kite nests):** This involves attaching GSM-GPS tags to the kites to track their movements over time. GPS tagged kites can be tracked for 2-3 years to understand their movement decisions over time. This information can be used to map nesting territories and track long-distance migrations. In association with remote monitoring of trail cameras fixed on the nests, GPS tagging can also be used to study kite behaviour in more detail.

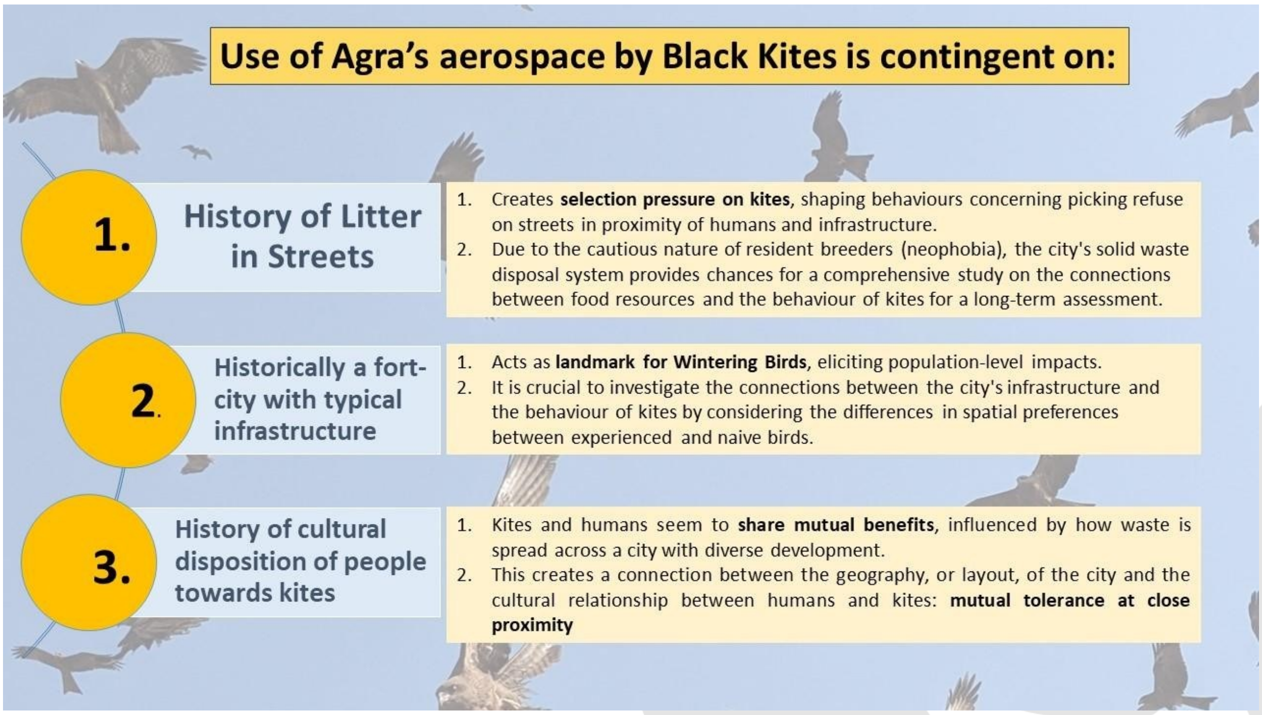

Fig. 7. Black Kite Adaptation in Agra: a historical perspective on biotic and abiotic factors influencing urban ecology.

Integrating a variety of monitoring methods into an IST can provide a more comprehensive understanding of kite behaviour and movement patterns. This information can then be used to develop more effective strategies for mitigating the threat that kites pose to aviation safety. For example, IST could be used to identify areas where kites are most likely to congregate, which could then be used to plan aircraft operations in those areas. Additionally, IST could be used to track the movements of resident versus migratory kites, which could help to identify problematic sub-populations (Fig. 8). Once these patterns are established in space and time, targeted removal or deterrence efforts could then be implemented. The synergy of these methods lies in their data- rich nature. The vast amount of information gathered can be analysed through AI and machine learning, offering crucial insights for bird strike mitigation strategies. This aligns with our ongoing research in Delhi, highlighting the importance of urban ecology in managing wildlife-human interactions in rapidly evolving cities.

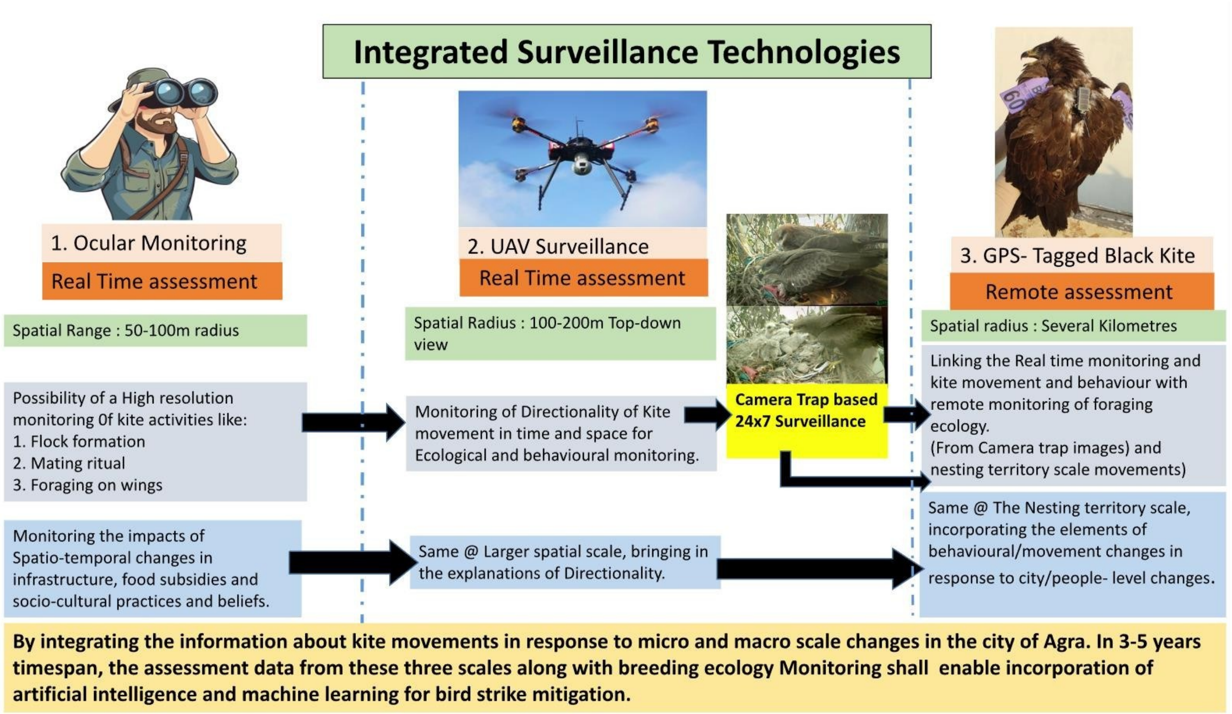

Fig. 8. Integrated Surveillance Technologies: a three-tiered approach to bird monitoring combining ocular monitoring, UAV surveillance, and GPS-tagged tracking for real-time and remote assessments of black kite behaviour and movement in urban environments.

Further, PAWS-Web seeks solutions to bird strike hazards by combining animal ecology studies with cutting-edge technologies, such as GSM-GPS telemetry and AI. We envision a future in which real-time bird-radar inputs, which are currently being planned by the Indian Air Force, synergistically enhance hazard prediction and prevention. Additionally, exploring planned waste management to regulate food subsidies for kites and other conflict species holds promising potential for reducing their attraction to airfields. Our research platform in Delhi exemplifies this multifaceted approach. By analysing the interplay of food availability, urban variables, and human factors across diverse urban settings, we have gained valuable insights into the factors that attract kites to airspace. Such integrated and longitudinal assessment paves the way for targeted mitigation strategies tailored to the specific vulnerabilities of Agra AFS.

Ultimately, understanding how kites perceive and utilise food resources within the urban environment is key to mitigating birdstrike threats. If successful, our Agra study can serve as a model for other South Asian airfields, potentially unlocking the power of GPS-tracked kites as remote data collection tools. This ability to remotely diagnose risk perception could revolutionise airspace management, not only improving aviation safety, but also contributing to the development of sustainable and wildlife-friendly cityscapes.

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