

Urban Heat Islands and the Seasonal Behavioural Shifts of Common Birds in Small Indian Cities

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Abstract- Urban heat islands are becoming an increasingly crucial factor in urban environmental change, affecting local temperature patterns and behavioral and ecological relationships of birds in urban areas. In small Indian cities, rapid construction of infrastructure, expansion of impervious surfaces, loss of vegetation cover and change in land use can increase thermal stress and change the availability of food, water and habitats for nesting. In this paper, we provide a critical narrative review of the interactions between urban heat islands and seasonal behaviour of common urban birds and the ecological dynamics in small Indian cities. We explore how hotter temperatures might affect daily behaviour patterns, foraging behaviour, drinking rate, shade-seeking, resting, nesting and reproduction in summer, monsoon and winter with particular attention on species that are adaptable, such as house sparrow, rock pigeon, house crow and common myna, as well as their thermal tolerance, habitat requirements and behavioural flexibility. The review also explores the potential implications of urban warming on resources available, breeding capabilities, species interactions, and the distribution of birds across urban microhabitats. There are also several limitations in the existing literature, and we find it very important to distinguish between behaviour of birds in urban heat islands from behaviour of birds influenced by urban climate change, food availability, habitat structure and other urban pressures. It is also clear that understanding these relationships is critical to the development of climate-sensitive urban planning strategies to protect bird habitats and to maintain ecological integration. It ends by identifying some of the studies which are seasonally resolved research and biodiversity-oriented interventions like urban tree cover, shaded green spaces and water. By linking urban climatology with bird behaviour, a conceptual framework for bird responses to urban warming is laid in this review.

Keywords- artificial light at night; urban insect decline; light pollution; nocturnal biodiversity; pollination; ecological disruption; urban sustainability

I. INTRODUCTION

Urbanisation is one of the major drivers of environmental change and transforms natural landscapes into roads, concrete structures, commercial areas and densely populated residential areas. This has a strong impact on local climate, vegetation cover, water availability and wildlife. One of the most well-known consequences of urbanisation is the formation of urban heat islands (UHIs) in which urban areas are hotter than rural or less developed areas. Building materials are more heavily used for hot weather (and hence they are more dense), less green and less evaporative in nature and heat is released by human activities. As much as urban heat islands are in humans' favour in terms of health and energy consumption, the ecological effects, particularly for wildlife, are also important. Birds are important

indicators of change as they are sensitive to different environmental conditions - temperature, habitat structure and availability of resources. Many bird species live in urban areas and can coexist with human populations. In Indian cities, the most common species are the house sparrow (*Passer domesticus*), rock pigeon (*Columba livia*), house crow (*Corvus splendens*), and common myna (*Acridotheres tristis*). Birds use different food options, nests, and habitats where they can adapt to disturbance of environment. Birds live in urban spaces and so their behaviour at the changing temperature in a warm environment and their behaviour can change which can have a positive effect on their survival in a warmer environment. Higher urban temperatures can affect birds in several interconnected ways and affect them in many ways. High temperatures can increase the energy expenditure of the body temperature that comes from

keeping the body temperature high, water use, and food intake and the time available for feeding, territorial defence and reproduction. Birds can behave behaviourally to take action towards cooler times of the day, seek shade, more access to water sources, less movement during the hottest hours or to cooler nesting places. Such behaviours can also reduce heat exposure and therefore reduce immediate exposure to the heat but these responses will depend on the availability of suitable vegetation, drinking water, food, shelter and shelter. Frequent or very high temperatures can also reduce the benefits of behavioural adaptation in urban areas with a lack of trees and fragmentation of green land, and long-term or more frequent urbanisation can also be harmful to birds' behaviour and not beneficial for them.

The seasonal variation in urban temperatures is particularly important in the Indian context. In summer, birds are exposed to high heat and water scarcity and in monsoon season that can affect temperature, humidity, rainfall pattern and food availability. Winter also brings with it different thermal conditions that may affect daily life and feeding and use of urban habitats. These seasons affect urban heat island effect and could lead to different behaviour depending on season and location. Birds for example may change their feeding times in hot weather, put on shaded vegetation more and/or choose different nesting and resting spots. However, such patterns can not be attributed to urban warming alone because rainfall, natural seasonal cycles, food availability, human disturbance, and habitat quality may also affect bird behaviour.

Small Indian cities provide an interesting venue for studying these relationships. While research on urban climate and biodiversity is often based on large metropolitan areas, smaller cities are experiencing changes in land use, construction density, road networks and vegetation cover. These urban areas might be made up of densely built neighbourhoods, markets, institutional campuses, residential gardens, agricultural margins, ponds and roadside trees. This variation can lead to unique microclimates over relatively short distances. Birds in these settings might also experience different degrees of thermal exposure depending on the availability of shaded areas, open

surfaces, water bodies and connected green spaces. However, the extent of these differences and the effects of those differences are something to be addressed rather than a city size-based hypothesis.

In order to understand the seasonal behavioural changes, it is important to distinguish between short and long-term behaviour changes. A bird that changes its feeding time or seeks shade during a heatwave might not be responding to the environment in a systematic way; it is not evolutionary adaptation and not reproductive success. Similarly, a species in a hot city environment does not mean it is immune to thermal stress. Behavioural changes can involve trade-offs like less time to feed (or more competition for water) or less time for parents to care for their young.

Although there is growing interest in urban ecology and climate-related environmental change, understanding the relationship between urban heat islands and seasonal bird behaviour needs evidence that separates urban thermal effects from broader seasonal and ecological influences. Birds' behaviour, feeding behaviour, shade use, drinking frequency, nesting and breeding should ideally be addressed in the context of local temperature conditions, vegetation structure, water availability and urbanization. This is especially possible in small Indian cities where local environmental conditions can vary very much between neighbourhoods and where findings from large metropolitan areas may not be directly transferable.

Based on these observations, the present paper provides a critical narrative study of the possibility of the urban heat islands and seasonal behavioural changes within the common birds of small Indian cities. The study investigates how thermal conditions might affect daily activities (foraging, drinking, shade-seeking, resting, nesting and reproduction) during summer, monsoon and winter and the ecological aspects of these behaviours and the relevance of urban green spaces and climate-sensitive planning. It aims to draw from urban climatology and bird behaviour ecology to develop a conceptual and practical context to ensure the survival of bird-friendly urban environments which are under high thermal stress.

II. REVIEW APPROACH AND CONCEPTUAL FRAMEWORK

We use a critical narrative review strategy to explore the relationship between urban heat islands and changes in behaviour of common birds living in small Indian cities. A narrative review is the right way to go for this paper as the evidence is from many different connected disciplines including urban climatology, bird behaviour, thermal physiology, urban biodiversity and seasonal changes in the environment. Rather than collect primary field data or perform statistical analysis, the paper draws on existing scientific knowledge to draw a conceptual picture of the implications of urban thermal conditions for bird behaviour in different seasons. It also assesses the current evidence and identifies research priorities specifically relevant to small Indian cities as well.

The review is based on the relation between urban structure, local thermal conditions, seasonal environmental variation and avian behaviour. Building and road expansion and development changes landscapes in the physical sense of buildings, roads, paved surfaces, and other impervious materials. This can affect heat storage, surface temperature, air circulation, as well as vegetation availability. Low tree cover and lack of soil moisture can also affect the natural cooling process and the shape and density of the buildings can affect the movement of air and the distribution of shade. Combined, these factors lead to differences in thermal exposure between built-up neighbourhoods and locations containing parks, gardens, roadside trees, ponds, and other green or blue spaces. In this context, urban heat islands are not the only influence on birds' behaviours, and they are less of a determinant of behaviour in this setting. Even more, we can also see that seasons change the temperature, humidity, rainfall, wind, food availability, predation risk, nesting opportunities and human disturbance, all of which are part of the urban heat island effect. For instance, in the summer the reduction of daytime activity may be related to heat avoidance, or to food availability or prey activity being delayed during the day. In the same way, the increased use of shade areas may indicate thermal avoidance in birds, but shade is also protection from predators or disturbances. Therefore, behaviour should be

interpreted in relation to other factors and not as an expectation from the urban heat island effect.

The review focuses on four familiar urban bird species: house sparrow (*Passer domesticus*), rock pigeon (*Columba livia*), house crow (*Corvus splendens*) and common myna (*Acridotheres tristis*). These birds show birds that thrive in the environment that we have created, but do not share the same ecological needs, feeding habits, nesting patterns and responses to environmental stress. The species are presented here as illustrative examples instead of as a whole that we expect to respond as a whole in a similar manner to increasing temperatures. Their inclusion does not mean that they are the only birds affected by urban warming; they are found to be in agreement in any small Indian city.

We consider seasonal behaviour in three broad periods: summer, monsoon and winter. For summer, excessive temperatures and evaporative water loss may affect activity schedules, shade-seeking and access to water. During the monsoon, rainfall, humidity, insect abundance and vegetation growth may modify thermal exposure and feeding opportunities. Winter may lead to changes in thermoregulatory requirements, daily activity patterns and resource usage. These seasonal categories were provided as a large-scale analysis framework and actual climatic conditions and seasonal transitions are different between regions and years. And in all cases, the monsoon is not going to provide a guaranteed thermal relief, since high humidity and hot weather may continue to affect birds.

The behavioural responses considered in this review include changes in daily activity timing, foraging duration, drinking frequency, shade selection, resting behaviour, habitat use, nesting site selection and reproductive timing. Such responses are evaluated in terms of their ecological benefits and costs. Seeking shade, for example, might reduce the direct exposure to solar radiation, but more inactivity during hot periods may reduce the opportunities for food. Similarly, introducing early-morning feeding may help birds avoid midday heat, and might put more competition for food during a shorter period of activity. Such trade-offs are important to see if

behavioural flexibility is sufficient to reduce the effects of thermal stress in different urban conditions.

The framework also distinguishes between quick behavioural responses and longer-term ecological outcomes. A change in activity or habitat use is a behavioural response and successful maintenance of body condition, survival, or reproductive performance is a more general biological outcome. Behavioural flexibility may assist birds to cope with short-term temperature fluctuations, but it doesn't necessarily show adaptation to persistent urban warming. Likewise, the differences in bird abundance between greener and more densely built neighbourhoods cannot be explained by temperature alone without considering habitat availability, food resources, nesting opportunities, or other environmental pressures.

Overall, this framework connects urban form and thermal conditions with seasonal environmental variation, behaviour and the potential for ecological impact. It can be used to understand how birds with common habitat would respond to urban warming and to distinguish study from one season or one city to the next. Our framework also allows for the identification of research priorities (e.g. seasonal bird behaviour observations, comparisons between built-up and vegetated areas and simultaneous measuring of local temperature, shade availability and water access). This evidence would help to understand how urban heat islands affect bird behaviour and could help to make smarter biodiversity-centered planning in small Indian cities.

III. URBAN HEAT ISLANDS AND THE THERMAL ECOLOGY OF COMMON BIRDS

Urban heat islands change the thermal ecosystem of birds living, hunting, resting and reproducing. The replacement of natural vegetation and permeable soil with buildings, roads and paved surfaces affects how much heat is absorbed, stored and released. Concrete, asphalt, brick and other materials can retain substantial amounts of heat during the day and release it gradually after sunset. Trees and other vegetation are also eliminated, and evaporative cooling is reduced as well. These processes result in warmer places for buildings and city areas with more

vegetation in the area of which it is built to be warmer. The intensity of this effect varies with the urban structure, weather conditions, season and the distribution of green spaces and water bodies. The impact of urban warming on birds is more than just on the ambient air temperature. Their thermal environment is also influenced by direct solar radiation, reflected heat from the surrounding surfaces, wind, humidity and access to shaded microhabitats. A bird resting in an exposed rooftop may experience a different level of heat exposure from a bird under a shaded tree canopy in the same neighbourhood. Similarly, ponds, garden vegetation and tree-lined streets can provide local refuge for an urban bird at high temperatures. Thus, the thermal conditions of birds in a city are not just about the temperature but also about the habitats they live in. Birds are endothermic animals in the sense that they control their body temperature through internal physiological processes. If the environment is suitable, heat exchange with the environment can occur without much physiological effort. But if the ambient temperature rises, birds will need to increase heat loss mechanisms to maintain a relatively stable body temperature. Depending on the species and environmental conditions, these mechanisms can include behavioural changes, posture changes, increased respiratory evaporation, and choosing cooler locations. High humidity can lead to evaporative cooling difficulties and low availability of drinking water makes it more difficult to stay water-balanced. Thus, heat exposure can create thermal and hydration problems when areas are densely built, and little vegetation or water is available. Behavioural flexibility in response to thermal stress is one of the most important aspects of avian responses to thermal stress. Birds might reduce activity during the hottest hours of the day, move to shaded areas, alter their orientation to the sun, increase drinking frequency, or concentrate feeding during cooler morning and evening periods to reduce exposure to high temperatures and help preserve energy and water. However, there are also trade-offs. Less daytime activity can limit feeding opportunities, so changing behaviour in the morning may increase competition among individuals or species. Birds that need to travel long distances to find food and water may also incur additional energy costs. The effectiveness of these responses can be influenced

by the severity and duration of heat exposure, individual condition, species-specific characteristics, and the availability of suitable urban habitat.

The types of urban birds that are common may experience the same conditions differently because they have different body sizes, diets, foraging behaviours, nesting habits and their use of human-made environments. The house sparrow (*Passer domesticus*), for example, frequently uses buildings, gardens, hedges and other structures that are associated with humans. Its access to food, nesting cavities, and shaded vegetation may influence how it responds to warm conditions. The rock pigeon (*Columba livia*) lives in buildings, bridges, rooftops and other structures. These habitats might provide nesting sites, but exposed roofs and ledges can be very hot. The house crow (*Corvus splendens*) is an adaptable omnivore for which urban food sources and resting areas are found, and the common myna (*Acridotheres tristis*) eats in open areas, lawns, roadsides and human-dominated areas. These differences suggest that the thermal impact of urbanisation should be examined in relation to each species' habitat use and ecological requirements rather than assuming a uniform response among all urban birds.

Vegetation is especially important in dampening the impact of urban heat islands. Trees provide shade, reduce local surface temperature and may even induce cooler microhabitats through evapotranspiration. Shrubs and dense vegetation also provide shelter, nesting space, and protection from direct sun exposure. Green spaces may also help birds acquire insects, seeds, fruits and other food sources. But the ecological benefits of vegetation depend on its structure, distribution and condition. A small, isolated patch of greenery may offer limited refuge if it lacks water or suitable nesting sites; a cluster of trees, gardens and parks can provide much more continuous access to resources. Thus, the conservation value of urban vegetation is not only in terms of the area covered but also its accessibility and suitability for different birds. Water availability is another important factor linking urban thermal conditions with bird behaviour. During hot and dry periods, birds may require more frequent access to drinking water, while some species might also use water for bathing or

other thermoregulatory behaviours. Natural water bodies in highly developed areas may be scarce, inaccessible, polluted, or separated from feeding and nesting sites. The potential to provide local benefits from artificial water sources can be quite attractive, but the quality of the water depends on cleanliness, reliable availability, and safe placement. As such, improving access to water should form part of a broader habitat-management strategy rather than being treated as a substitute for vegetation and other essential ecological resources.

Urban heat islands can also have effects at night. Buildings and paved surfaces may release stored heat after sunset, reducing the extent of nighttime cooling in some urban locations. On warm nights, resting conditions and birds' recovery from daytime heat exposure may be affected. However, nighttime temperature patterns are not uniform across all urban habitats, and the biological consequences vary by species, season, and local conditions. In addition, artificial lighting and noise can independently affect activity and resting behaviour, making it important to distinguish the effects of thermal conditions from other aspects of urban environments. A more challenging aspect is to know if the observed differences in behaviour of birds in cities are directly related to urban heat islands. Birds in densely built areas may also be different from those in green areas for temperature reasons as well as for food availability, human feeding, traffic, predators, nests and disturbance. Rainfall, humidity, vegetation and prey abundance can also change daily. For instance, it may be possible that more frequent drinking visits in summer are associated with higher temperatures, less natural water availability or both. Similarly, lower midday activity might be related to avoidance of heat but may be indicative of the usual rhythm of daily activity. Therefore reliable interpretation should be based on comparison of local temperature observations and habitat conditions across places and seasons. Overall, urban heat islands can affect the thermal ecology of common birds in terms of heat exposure, water demand, habitat use and costs for daily life. But the magnitude and direction of these effects will vary from species to neighbourhood to season. Vegetated areas, shaded resting sites and water access may reduce thermal exposure but their

effects will depend on the larger ecological conditions in the urban environment as well. By building these interrelationships, the questions can be answered about how birds are affected by urban warming in summer, monsoon and winter and how birds respond to any change.

IV. SEASONAL BEHAVIOURAL SHIFTS IN URBAN BIRDS

There are seasonal changes in temperature, rainfall, humidity and resource availability that affect the daily lives of birds in urban environments. They are probably most concerned in cities where buildings, paved surfaces and less vegetation make them more susceptible to the local temperature climate and may be more responsive to these changes. Birds might respond to seasonal variations in the environment by changing their feeding schedule, resting times, habitat use, drinking and nesting behavior. However, the responses to seasonal heat may not be the same for different species or places. The house sparrow (*Passer domesticus*), rock pigeon (*Columba livia*), house crow (*Corvus splendens*) and common myna (*Acridotheres tristis*) are different in their ecological requirements and use of urban habitats and their responses to heat conditions are also different. We have to understand the direct impacts of temperature and the effects on the food, water, vegetation, and human activities in relation to these shifts.

1. Summer: Heat Avoidance and Changes in Daily Activity

Summer is likely to be the most challenging season for many urban birds in northern India because high daytime temperatures can coincide with low water availability and longer exposure to solar radiation. In densely populated neighbourhoods, heat retained by buildings and paved surfaces may increase thermal exposure. Birds may concentrate feeding and other active behaviours during the cooler hours of early morning and late afternoon, while decreasing movement during the hottest part of the day. Such adaptations could decrease heat gain and reduce the energetic costs of activity during times of high environmental temperature. Shade-seeking is another possible behavioural response in summer. Trees, shrubs, covered spaces and shaded building structures

may offer temporary refuge from direct solar radiation. Birds may change their resting locations throughout the day depending on the movement of shade and the availability of cooler microhabitats. However, this response needs to be based on the distribution of vegetation and also sheltered areas. In neighbourhoods with few trees in place, there may be limited rest areas and competition for shaded areas in the neighbourhood.

Access to drinking water may also be more important in the heat. When temperatures are high birds may visit water sources more often, but the response of birds will depend on species, diet, physiological status and environmental conditions. Natural water sources, garden water sources and other easily available water sources may also affect the way birds use urban spaces in summer. At the same time, artificial water sources that are poorly maintained may pose hygiene risks. These water sources should therefore be taken into account, along with shade and vegetation, when determining the habitats of birds in urban areas.

Changes in feeding behaviour may put more pressure on birds to make some more food choices. Birds may prefer to forage away from the sun to avoid heat, so they are less likely to eat in the sun. A shorter period of eating could lead to less energy for birds raising chicks or defending territories, and thus to less energy consumption. Animals that depend on food provided by humans may respond differently to food sources in the face of more insects, seeds or other natural resources. The house crow and rock pigeon, for instance, might depend on a wide range of human sources of food while those of the house sparrow and common myna may be dependent on particular combinations of seeds, insects and other local resources. These differences should be looked at rather than as being the norm in the assumption that one species is more heat tolerant than another.

2. Monsoon: Changing Humidity, Food Availability, and Habitat Use

The monsoon season brings with it another set of environmental conditions. Rainfall may lower surface temperatures and replenish water resources, and vegetation growth may enhance shelter and food availability. During this time, insect activity and

abundance may change, and the feeding behaviour of insectivorous birds and species that consume insects in their diets could change. For urban birds, gardens, parks, roadside vegetation and water bodies could become important foraging sites as the structure and productivity of local habitats change.

But the monsoon doesn't necessarily remove thermal stress. High humidity can reduce evaporative cooling, and periods without rainfall may still be hot. Birds may also have problems around heavy rain, strong winds, wet plumage and lack of access to exposed feeding sites. So their behaviour may be characterized by trying to avoid heat, shelter from rain and still obtain food. Birds might change their resting area, use dense vegetation or overhangs and change the timing of foraging according to immediate weather conditions.

The monsoon may also affect nesting and reproductive behaviour. The availability of insects and other food resources can affect the ability of adult birds to raise their young, and rainfall and humidity may affect nesting sites. Breeding patterns for different species and geographical regions are still not obvious, and there would be no way to assume all urban birds reproduce at the same time or respond to monsoon conditions. The role of urban heat islands in these processes also needs to be carefully separated from the larger effects of rainfall, food availability and seasonal breeding cycles.

The monsoon can also create considerable variation between small Indian cities where the monsoon can affect neighbourhoods strongly. Areas with mature trees, gardens, and water bodies in mature commercial areas might provide different feeding and resting areas, and therefore the quality of the urban environment would also be impacted by waterlogging, vegetation removal and drainage issues. Those differences suggest that seasonal studies should include not only temperature but also local rainfall and humidity, vegetation structure and feeding and nesting sites.

3. Winter: Thermal requirements and resource use

Winter generally presents different thermal conditions from summer, but the severity of cold varies from region to region and year to year. In northern Indian

cities, lower temperatures could affect the timing of morning activity, location of resting sites and the amount of time birds spend feeding. Birds may have to balance the energetic need to keep body temperature and food to feed themselves. Sunny locations, sheltered ledges, dense vegetation and other protected microhabitats may be used for resting or avoiding cold winds.

The urban heat island effect might also contribute to some of the milder winter temperatures by keeping urban areas warmer in built-up areas than those in the rural regions. There may be some impact on the habitats that birds use and the activity they do in cities, but this is dependent on the species and city environment as well. Warmer conditions should not be assumed to be a good thing in general for birds. Urban habitats could have less natural vegetation, less space for feeding or other environmental conditions which reduce bird numbers. And the effect of warmer urban nights may differ from daytime temperatures, making it important to consider daily temperature variation rather than seasonal averages alone. Feeding behaviour can also change during winter as insects, seeds, fruits and human-provided food may vary. Birds might spend more time searching for food where natural resources are few and far between, or they may focus on feeding in locations where they have access to food well. House sparrows, rock pigeons, house crows and common mynas will respond differently to different diets and foraging strategies. But any seasonal change that is apparent must be distinguished from the changes in human food provisioning, breeding status and the relative abundance of competing species in the region. Winter also allows us to explore how urban thermal conditions affect the selection of resting and roosting sites. Buildings and sheltered structures can provide protection from wind, and trees and shrubs can provide cover and suitable resting sites. The importance of these habitats will vary with weather and availability. Comparing densely built areas to greener areas may help to understand if temperatures in these locations correspond to changes in bird activity and habitat use during cooler seasons.

4. Interactions Across Seasons and Differences Among Species

Seasonal behavioural changes should not be viewed as an independent response to temperature. Food availability, water access, habitat structure and when females are fertile are all affected by summer heat, monsoon rainfall and winter cooling. A good shade location in summer may also provide nests for breeding and shelter in winter. Similarly, the value of a water body is affected by rainfall, surrounding vegetation and the availability of other water sources. It is important to see species-specific differences in these relationships. Nesting cavities, shrubs, seeds and insects are all available for the house sparrow. The rock pigeon frequently nests in buildings and other structures that can provide nests but heat exposure to the bird is inevitable if the habitat is not shaded. The house crow's adaptability to the environment can be used to take advantage of different urban resources and the common myna is likely to benefit from open areas foraging and sheltered nests. These are ecological and not necessarily a thermodynamic prediction of the bird's response to a thermal situation; comparisons are to be made with observations in a similar environment.

It is also important to distinguish behavioural flexibility from adaptation. Changing feeding times, seeking shade or staying in a different place for the day may cause birds to face very brief exposure to bad circumstances but these behaviours can cost if they reduce feeding opportunities or increase competition. Persistent heat can also be more difficult in the city where there are no good refuges or water sources. The presence of behavioural adjustments does not prove that birds are able to survive and reproduce in this city environment and live longer into the future. Winter behavioural shifts are, on the whole, a good way to observe how common birds respond to changing thermal conditions in small Indian cities. Summer may increase the importance of heat avoidance, shade, and water; monsoon may change shelter and food availability; winter may change feeding needs and the setting of resting sites. The extent of these responses will depend on local climatic conditions, species-specific ecology, and available urban habitats. Long-term, seasonally resolved observations that combine bird behaviour with temperature, humidity, rainfall,

vegetation and water availability are therefore crucial in order to understand how much urban heat islands affect these patterns.

V. ECOLOGICAL IMPLICATIONS AND ADAPTATION IN SMALL INDIAN CITIES

The behavioural responses of urban birds to the rise in temperatures have implications that extend beyond just heat avoidance. Changes in feeding schedules, resting patterns, water use, habitat selection, and reproductive activities may influence individual condition, species interactions, and the ecological functioning of urban environments. In small Indian cities, these consequences are shaped by the interaction between urban development, seasonal climate, vegetation cover, and the availability of suitable habitats. While behavioural flexibility may help some birds cope with short-term environmental stress, its benefits depend on whether birds can access the resources necessary to maintain their daily activities and reproductive requirements.

1. Implications for Feeding and Energy Balance

One of the ecological effects of heat-related changes in behaviour is to change the opportunities for feeding. Birds that are less active in the hottest hours will concentrate foraging in the cooler parts of the day. The reduction of thermal exposure can decrease this time but can also shorten the time for obtaining food. The situation can be even more important when birds are feeding chicks, maintaining body condition, or competing for limited resources. If more than one species moves their activity to the same part of the day, there will be more competition for food but the degree of competition will depend on the availability and distribution of resources. Urban environments have very different food resources. Markets, residential areas, parks, gardens, and institutional campuses may have discarded food, seeds, fruits, and insects. Human-produced food may be used by the house crow and rock pigeon, but house sparrows and common mynas might have different food sources from natural and human sources. This could affect how birds can adjust their feeding schedule when it gets hot. But access to a lot of food is not enough to remove thermal stress, and food availability alone is not enough to show

whether a population is weathering urban warming well.

2. Effects on Nesting and Reproductive Performance

Elevated temperatures may influence nesting behaviour and reproductive performance through direct heat exposure and indirect changes in food and water availability. Nest sites located in exposed rooftops, metal structures, or poorly ventilated cavities may experience conditions different from those in shaded vegetation or sheltered building locations. Excessive heat within or around nests may increase the thermal challenges faced by adults and developing chicks. In response, some birds may alter nest-site selection, modify parental activity, or adjust the timing of visits to nests. The effectiveness of these responses will depend on the species, nest structure, local microclimate, and the availability of alternative nesting sites.

3. Changes in Adult Activity May also Affect Parental Care

If high temperatures restrict foraging or require adults to spend more time avoiding heat, the frequency and timing of food delivery to chicks could change. Similarly, the availability of insects and other food resources may vary with seasonal weather and habitat conditions. These interacting pressures suggest that reproductive outcomes should be considered alongside behavioural observations. Nevertheless, the relationship between urban heat islands and breeding success should not be assumed to be uniformly negative or identical across species; it requires direct evidence from particular locations and breeding periods. Urban Green Spaces as Thermal Refuges. Urban green spaces can play an important role in reducing local thermal exposure and maintaining bird habitat. Trees provide shade and may lower surrounding temperatures through evapotranspiration, while shrubs and ground vegetation offer shelter, nesting locations, and potential food resources. Parks, gardens, institutional campuses, roadside vegetation, and tree-lined residential streets may therefore provide cooler microhabitats within otherwise densely built landscapes. Their value depends on vegetation density, plant diversity, water availability, and the degree to which green spaces are connected. In small

Indian cities, green spaces may be unevenly distributed. Older residential neighbourhoods and institutional areas may retain mature trees, while newly developed commercial zones may contain extensive paved surfaces and relatively little vegetation. This variation can create differences in the availability of thermal refuges over short distances. Protecting existing mature trees, planting locally appropriate vegetation, maintaining shrubs, and improving the continuity of green spaces may help birds access shelter and resources throughout the year. However, tree planting should consider species suitability, water requirements, maintenance, and the habitat needs of local birds rather than focusing only on increasing green cover. The ecological benefits of green spaces also depend on their quality. A small, isolated lawn with limited tree cover may offer fewer resources than a more structurally diverse space containing trees, shrubs, and native plants. Similarly, heavily disturbed parks may provide limited refuge if vegetation is regularly removed or birds are frequently disturbed. Urban planning should therefore consider both the area and the ecological structure of green spaces, including their potential to support feeding, resting, and nesting across different seasons. Water Availability and Habitat Management. Reliable access to clean water may become increasingly important during hot and dry periods. Natural ponds, wetlands, drainage channels, and other water bodies can provide drinking opportunities and support insects and other food resources. However, urban development may reduce or degrade these habitats through encroachment, pollution, drainage alteration, and the removal of surrounding vegetation. Protecting existing water bodies and maintaining their ecological condition may therefore support urban bird communities while contributing to broader environmental benefits. Artificial water sources may provide supplementary support where natural water is scarce. Their usefulness depends on regular cleaning, reliable water replacement, suitable placement, and protection from contamination. Water points should be positioned where birds can access them safely and where routine maintenance is feasible. They should complement, rather than replace, the conservation of natural water bodies and vegetation. Habitat management should also recognise that concentrating birds around poorly

maintained resources may increase risks associated with contamination or disease transmission.

4. Species Differences and Ecological Interactions

Urban warming may alter interactions among species by changing the timing and location of feeding, resting, and nesting activities. If several species increasingly use the same shaded locations or water sources during hot weather, opportunities for competition may increase. Conversely, differences in body size, diet, foraging methods, and habitat preferences may allow some species to use different resources or microhabitats. The house sparrow, rock pigeon, house crow, and common myna should therefore be evaluated separately rather than treated as a single group with identical responses to thermal stress. If humans are more aggressive, then birds that gather around water points, shaded public spaces, markets or food-disposal sites will experience more human disturbance. Human feeding as a source of food for some species may be more than that but it will also have a negative effect on natural behaviour and birds will be concentrated in certain areas. That makes it difficult to attribute changes in bird numbers or activity only to the urban heat islands. A proper ecological assessment should incorporate both thermal conditions and the environmental pressures of urban life.

What will be the implications for climate-sensitive urban planning?

Environmental impacts of urban heat islands make biodiversity more important for urban development. Keeping trees in place and protecting ponds and wetlands, reducing paving and installing shaded public spaces may help to balance local temperature and birds have the necessary habitat to survive. The use of permeable surfaces and vegetation where possible would help in cooling the city but individual measures depend on the design of the city and its environment. Planning should also focus on the creation of connected networks of green spaces and not just on isolated parks. Small Indian cities could also take such measures into road development, residential planning, institutional campuses, public parks and even water body restoration. Current mature trees should be taken into account. Newly planted trees may take a long time to develop the same shade and habitat

structure. Building design should also account for nesting opportunities and thermal exposure, so as to avoid any interventions that could unintentionally create ecological traps or create risks to wildlife. This should be informed by local environmental evaluations and the status of resident bird species.

In general, the ecological impact of urban heat islands depends on thermal exposure, behavioural flexibility, habitat quality and density of resources. Change in activity can help birds cope with heat stress early on, but for the long-term survival of the birds it depends on whether food, water, shelter and nesting sites are available in the environment. For small Indian cities, preserving structurally diverse green spaces, protecting natural water bodies and incorporating bird habitat into climate-sensitive planning are the practical options to keep environmental pressures low. Their effectiveness should be evaluated by monitoring local temperatures, bird behaviour, habitat use and, if possible, reproductive outcomes.

VI. RESEARCH GAPS AND FUTURE DIRECTIONS

Although urban ecology and bird behaviour research have become much richer, there are still significant questions about the role of urban heat islands and seasonal behaviour change in common birds, particularly in small Indian cities. The existing literature includes urban climatology, thermal physiology, habitat selection, and bird behaviour. Research carried out in large metropolitan areas or outside India may provide useful theoretical and methodological guidance, but cannot be generalized to smaller Indian cities where the urban form, seasonal weather, vegetation, water availability, and human-bird interactions will be different. A more holistic approach is needed to understand how local thermal conditions affect the behaviour of birds and whether the behaviour changes are of any ecological meaning.

One critical research gap is the relatively low integration of local temperature measurements with systematic bird behaviour observation. In studies that either record bird abundance or activity without temperature and habitat data, they might not be able to differentiate thermal effects from other

environmental effects. Future work should compare densely built areas to greener ones such as parks, institutional campuses, residential gardens, and neighbourhoods with trees older than 100 years. Air temperature, surface temperature, humidity, and shade availability could be used to distinguish thermal exposure. Records of bird activity in the same locations would allow researchers to determine if feeding, resting, drinking, and shade-seeking habits are consistent with local environmental conditions.

Seasonal coverage is also a very important research need. Bird behaviour may be more dynamic in summer, monsoon, and winter, but observations during one season will not show how the patterns differ throughout the year. Future work must be based on repeated observations during different seasons and may also be carried out over many years. Such research could find out whether birds are always migrating in the direction of cooler times during hot seasons and if the water availability determines how they feed themselves or shelter themselves or if monsoon conditions affect them. Long-term observations would also help distinguish recurring seasonal patterns from responses to unusually hot days, heatwaves, or rainfall fluctuations.

Another problem is to draw a line between urban heat islands and other related pressures associated with urbanisation. And although dense development can increase temperatures, noise, traffic, vegetation structure, food availability, and human disturbance can also affect bird behaviour independently or in some way in relation to thermal conditions. For example, morning activity could be affected by temperature and noise, and the variance in the number of birds in two neighbourhoods may be explained by different nesting opportunities or food sources. Therefore, future studies should monitor relevant environmental factors and use appropriate comparative designs, and not attribute every change to urban warming.

Species-specific evidence is needed as well. The house sparrow (*Passer domesticus*), rock pigeon (*Columba livia*), house crow (*Corvus splendens*), and common myna (*Acridotheres tristis*) are all good examples of birds living in human-modified environments, but their ecological needs are different. Their responses may be

influenced by diet, body size, nesting behaviour, habitat use, and access to human resources. Research should investigate in this field, not just the common urban species that will have the same thermal tolerance or behaviour flexibility.

Another major gap is how behaviour is related to biological outcomes. A bird resting in shade or changing its feeding schedule suggests a behaviour change, but does it mean that the behaviour is good for survival or not? Future work might consider the interplay of thermal exposure with nesting site conditions and parental feeding, chick development, and body condition in the spring, summer, and fall, and so on in line with ethical and practical considerations. It would also help clarify between short-term avoidance of heat and long-term adaptation to the environment. It would also help us understand if, in the absence of these factors, apparently flexible species are paying some hidden costs when the temperatures are high or the environment is not suitable to shelter them in. The research methods should be designed to capture the variation in small cities. Rather than treating a city as one thermal environment, studies could compare different neighbourhood types, such as commercial centres, residential neighborhoods, institutional campuses, parks, and areas close to water bodies. Similar behaviour observations at different times of day could help to make comparisons more reliable. Temperature and humidity sensors, thermal mapping, and geospatial information about vegetation and impervious surfaces may be used as evidence as well. Where data is robust enough and there are resources, repeated observations and statistical tools could help to identify associations between environmental variables, bird behaviour, and habitat characteristics. Such methods will enhance future empirical studies without implying that this narrative review itself has collected or analysed primary information. Citizen science programmes would provide other sources of information about the seasonal bird activity and distribution. Local birdwatchers, students, educational institutions, and conservation organisations might bring standardised observations from different neighbourhoods. But citizen science records need to be interpreted carefully because observation effort, observer skill, time of day, and access to certain

locations could affect data. Clear protocols, consistent species identification, and observation conditions would be helpful, and researchers, local institutions, and municipal authorities might also be supportive of the ongoing monitoring of urban biodiversity. Finally, future research should look at whether actual urban interventions lead to tangible benefits for birds. Tree planting, managing mature vegetation, pond restoration, maintaining water supply, and developing connected green areas are ways to improve habitats in urban areas. But they should be assessed and not just assumed in this context. Bird activity and habitat usage before and after intervention, or even between locations with different vegetation and shade, should be compared. These comparisons would help to know which parameters are best suited to local climate and environmental conditions, and how they benefit different species.

More progress is needed in seasonally focused, species-specific research that combines bird observations with local thermal conditions and habitat. One particular focus could be the separation of urban heat island effects from other urban pressures, the ecological costs and benefits of behavioural flexibility, and the benefits of habitat management. This would bridge some of the gaps in urban bird ecology in small Indian cities and provide a more reliable evidence base for biodiversity-sensitive planning in changing climate conditions.

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