A review of threats to Indian birds and their habitats

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Abstract

India's avifauna faces a complex array of anthropogenic and emerging threats that affect both species and ecosystems. This review synthesizes current knowledge on eleven major threats, including land-use change (monocultures, urbanization, ecosystem degradation, and sand mining), energy infrastructure (wind farms and power lines), environmental pollutants (pesticides, veterinary pharmaceuticals, and heavy metals), avian diseases, illegal killing and trade, and climate change. It evaluates their mechanisms, documented impacts, and cascading ecological consequences. Drawing on peer-reviewed studies, grey literature, government reports, and expert knowledge associated with the *State of India's Birds*, we highlight spatial patterns of habitat loss, community-level shifts, and mortality from collisions, poisoning, and disease. Despite notable case studies (e.g., vulture die-offs from diclofenac, sandbar-nesting failures in the National Chambal Sanctuary, raptor displacement at wind farms), we find a critical paucity of systematic, long-term, and landscape-scale research linking specific threats to population declines. We recommend targeted field studies across under-represented biomes, establishment of pollutant and disease monitoring networks, integration of sensitivity-mapping tools into infrastructure planning, and policy measures such as extending NSAID bans and strengthening enforcement against illegal sand mining and wildlife trade. By identifying key knowledge gaps and proposing evidence-based conservation actions, this review aims to inform conservation priorities and promote coordinated efforts to safeguard India's bird diversity in an era of rapid environmental change.

Introduction

Approximately 49% of extant bird species worldwide (5,412) are known or suspected to be undergoing population declines (BirdLife International 2022). Changes in land-use patterns that result in the conversion of grasslands, wetlands, and forests for human use, infrastructural development, environmental pollutants, ecosystem degradation, climate change, and widespread suburban sprawl have the potential to significantly alter bird communities across India. While most of these anthropogenic threats negatively impact bird assemblages as a whole, other more species-specific threats also exist, such as illegal killing and bird trade, which disproportionately affect endangered species. Avian diseases are also emerging as a significant problem, exacerbated by India's warming climate and the increased risk of infection due to growing international trade of wild bird species. Interestingly, even 'green' infrastructure such as wind farms and solar energy installations, when not planned or located with adequate ecological sensitivity, can significantly affect local avifauna. Their impacts arise not only from the extensive natural habitats they occupy, but also from the growing network of power lines required to transmit energy from these installations.

This review seeks to highlight the key direct threats to bird species in India that have the potential to affect populations. These direct threats relate to the use and management of land and water, the exploitation or management of species and ecosystems, and other additional sources of stress (Salafsky et al. 2025). Together, these factors are known to have a negative influence on the bird populations or their habitats. This is not a comprehensive review; rather, it examines a subset of historically significant and recently emerging threats to bird species, habitats, and assemblages, for which sufficient information is available.

In this review, there is limited information robustly linking bird population trends with specific threats. Therefore, we outline key areas for research where gaps in understanding remain. Where specific threats are well-documented in India, we provide suggestions for immediate policy improvements, stronger implementation of existing legal frameworks, and actions needed from governments, non-governmental organizations, and civil society, while encouraging scientists and other academic institutions to focus further studies on the drivers of population decline.

This review is an outcome of the second iteration of the State of India's Birds (SoIB 2023). While we presented a brief version of the threats to bird species, habitats, and assemblages in the SoIB report, this review provides a comprehensive synthesis, incorporates additional evidence and expands on previously identified threats, and introduces additional emerging threats.

Methodology

We compiled a comprehensive body of information on threats to Indian birds from diverse sources. Research papers were identified through systematic searches using various search engines and academic databases, applying combinations of relevant keywords to ensure the inclusion of a wide range of credible and peer-reviewed studies. Additionally, grey literature, including scientific reports, technical documents, and policy papers from government and non-governmental organizations, was reviewed to incorporate additional insights. To further enhance the depth of our analysis, we also included unpublished inputs from field experts, researchers, and conservationists actively engaged in the study and conservation of Indian bird species.

Rather than attempt an exhaustive catalogue of all pressures on Indian birds, this paper focuses on selected themes for which research evidence exists and that have demonstrable impacts. These are reviewed in terms of their ecological mechanisms and documented consequences, followed by discussions on research needs and possible mitigation pathways. In doing so, we hope this review contributes to a deeper understanding of how to safeguard India's avian biodiversity.

Results & discussion

1. Monoculture plantations

Monocultural plantations (hereinafter, monocultures) include plantations of tea, cardamom, rubber, teak, or other species. Since such monocultures are created through the large-scale clearance or modification of forests and grasslands, they are likely to affect native birds. In addition to traditional plantation crops such as tea and rubber, newer tree crops such as oil palm have recently been introduced in India. Here, we focus on monocultures of perennial crops such as tea, oil palm, and rubber **[134, 135]**. Annually harvested agricultural crops are not considered here, although these could also be considered as monocultures.

Photo: Ramesh Kumar Selvaraj

134. Monoculture tea plantations replace structurally diverse forest habitats, as in the Manjolai area, Western Ghats, Tamil Nadu.

Photo: Ghazal Shahabuddin

135. Monoculture teak plantations simplify forest landscapes, as in the buffer zone of the Corbett Tiger Reserve, Uttarakhand.

The area under traditional plantation crops such as those of tea, teak, and rubber has increased during the current millennium. For instance, the area under tea increased from 5,214 sq. km to 6,366 sq. km between 2003 and 2020 (Raman et al. 2021:294). Certain other historic plantations such as wattle, both *Acacia mearnsii and A. dealbata,* expanded considerably in the 20th century in the southern Western Ghats and have since become invasive (Nayak et al. 2023). More recent plantation crops such as oil palm have also undergone considerable expansion in area. For example, the land covered by oil palm plantations increased thirtyfold between 1991 and 2015. Most of this expansion has taken place in the tropical rainforest biome (Srinivasan et al. 2021). The ongoing expansion of oil palm in biodiversity hotspots such as the Andaman and Nicobar Islands and the eastern Himalaya has regional implications for biodiversity, as it threatens several primary forest bird species. Apart from deliberate plantation activity, a range of reforestation programmes across India have also had unintended consequences through the spread of monocultures. A case in point is the planting of the exotic *Prosopis juliflora* in vast swathes of deserts, grasslands, and tropical dry forests which has resulted in low-diversity monocultures, due to the invasive nature of this species.

In India, research has been limited both in terms of the range of monoculture types studied and the number of study sites. Coffee is one of the better studied plantation crops (Anand et al. 2008; Chandran & Vishnudas C. K. 2018; Chang et al. 2018; Chandran et al. 2025). Despite the vast expanse of tea plantations in India, this commercial crop has been studied in detail only in the Anaimalai Hills of the southern Western Ghats (Raman et al. 2021). Multi-season surveys have been carried out on woodpeckers in old teak plantations adjoining sal forests in the Shivalik range in Uttarakhand (Kumar et al. 2011). More recently, with the introduction of oil palm, avifaunal studies have been undertaken by Mandal & Raman (2016) and Srinivasan et al. (2021) in the north-eastern hill states. Birds in chir pine monocultures have been studied by Shahabuddin et al. (2021) in the western Himalaya. Most studies have been able to pinpoint the species, habitat guilds, and feeding guilds that are affected by the conversion of multispecies forests to monocultures. Other important plantation systems such as rubber, arecanut, coconut, eucalyptus, acacia, casuarina, and diverse horticultural plantations remain poorly studied, particularly with respect to long-term population trends, functional diversity, and landscape-scale responses of bird communities.

Why do monocultures affect birds and their ecology? Based on numerous studies over the years, it is now well-established that bird diversity and composition are strongly affected by the reduced structural complexity of monocultures compared with forest, as well as by management practices such as the use of pesticides, the replacement of diverse tree cover with exotic shade trees, weeding, and cleaning. Plantations lack vertical complexity due to the need to maintain even-aged stands (trees of similar ages) for ease of management and harvest, often leading to the loss of large-sized trees. Horizontal heterogeneity is reduced by the planting of single species across large tracts, a system that limits the growth of other trees, shrubs, and herbs. The use of herbicides and pesticides together with cleaning and weeding further intensifies the adverse impacts on birds. Reduced canopy cover (shade), low basal area, and fewer large native trees also affect birdlife. Finally, harvest operations, which involve the extraction of biomass such as leaves, fruit, wood, and other non-timber forest products, drastically reduce the availability of niches and resources for birds used for nesting, roosting, and feeding. Birds are dependent on insect, fruit, and nectar resources that may not be available throughout the year in monocultural systems. For instance, nectar and fruit resources may be concentrated in a single season and be largely unavailable during the rest of the year, due to the lack of tree diversity.

A number of field studies show that monocultural plantations host fewer bird species than adjoining forest ecosystems (Fig. 1). Monocultures such as oil palm support only 14% of the bird species found in comparable rainforests in Mizoram (Mandal & Raman 2016). Teak plantations support only 54% of the rainforest bird species in Mizoram and 50% of the total woodpecker species found in old-growth sal forests in Uttarakhand (Kumar et al. 2011; Mandal & Raman 2016).

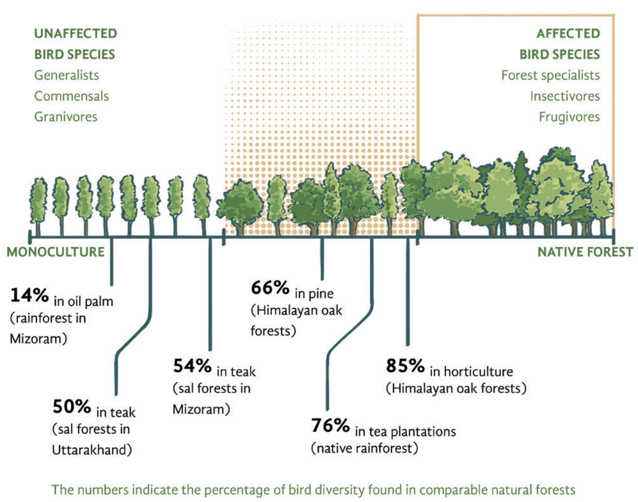


Fig. 1. Bird species seen in monocultures in comparison to the natural habitat. Source: State of India's Birds

It is important to note that while bird diversity is adversely affected in monocultures, the degree of local species loss depends on the type of plantation considered, the surrounding landscape, as well as the management practices adopted within plantations. Certain types of commercial plantations can support rich bird communities. For instance, tea plantations with a diverse cover of native shade trees show higher bird abundance and richness than conventional tea plantations (with pesticide use) with a single tree species providing shade (Raman et al. 2021). Bird species richness in conventional tea plantations was 76% of that seen in adjoining native rainforest patches (Raman et al. 2021). Similarly, pine monocultures harboured as much as 66%, and horticultural plantations 85%, of the bird diversity of adjoining Himalayan oak forests (Shahabuddin et al. 2021).

While monocultures may support comparable species richness in some cases, they often differ markedly in species composition—that is, in the types of species able to survive in these altered habitats. For instance, the number of rainforest bird species recorded in conventional tea plantations (with pesticide use) established in place of intact rain forest was only one-fourth of that in intact rainforest, while overall species richness was not as drastically affected (Raman et al. 2021). While bird species richness in horticultural plantations amounted to as much as 85% of that in protected hardwood forest in the western Himalaya, pine monocultures hosted a radically different set of species, dominated by open-country generalists and forest edge species (Shahabuddin et al. 2021). Importantly, the density of forest specialists declined by more than 90% in pine monocultures compared with hardwood oak forests in this region, while that of forest generalists was not affected. Compared to other major cash crops in the Western Ghats, such as areca and rubber, coffee agroforests support higher overall avian richness, higher endemic bird richness, and greater densities of most foraging guilds (Chang et al. 2018).

The change in composition can be ascribed to differential effects on different guilds and taxa. For instance, insect-eating birds have been found to be especially vulnerable to local declines in monoculture habitats (Shahabuddin et al. 2021). This may be attributed to the reduced availability of insects, resulting from pesticide use, poor canopy cover, low tree diversity, and simplified vegetation structure. Insectivores include a wide range of sallying and gleaning species such as warblers, robins, flycatchers, and tree-creepers, as well as birds feeding on the forest floor, such as thrushes and babblers, which depend on a constant supply of insects, in turn require complex and diverse vegetation, both in terms of structure and composition. Observations indicate that there is also a paucity of large, old native trees in monocultures, leading to the loss of microhabitats and niches for forest birds.

Another category of birds, namely forest specialists, defined as species that preferentially inhabit high-quality (old-growth) forests, is especially vulnerable to local declines when forests are converted to plantations. This is evidenced by the low species richness and reduced abundance in plantations compared with adjacent forests (Raman et al. 2021; Shahabuddin et al. 2021). Rainforest specialists such as the Malabar Trogon *Harpactes fasciatus,* Asian Fairy-bluebird *Irena puella* and the Brown-cheeked Fulvetta *Alcippe poioicephala* are among the species that are largely absent from tea plantations in the Western Ghats (Raman et al. 2021). A narrowly specialized taxon such as the Rufous-bellied Woodpecker *Dendrocopos hyperythrus*, a type of sapsucker that is dependent on tree sap in Himalayan broadleaf forest, is largely absent from horticultural plantations and pine stands at the same altitude (Shahabuddin et al. 2021). Modified landscapes and monoculture plantations thus tend to retain habitat generalists, while forest specialists decline, leading to bird communities increasingly dominated by generalist and open-country species (Raman et al. 2021; Shahabuddin et al. 2021).

2. Habitat degradation

Habitat degradation is one of the major drivers of biodiversity loss globally and affects a wide range of ecosystems including forests, wetlands, grasslands, scrublands, deserts, and coastal habitats (IPBES 2019). Human activities such as logging, excessive biomass extraction, altered fire regimes, overgrazing, invasive species spread, hydrological modifications, pollution, infrastructure expansion, agricultural intensification, and fragmentation continue to alter natural ecosystems worldwide (FAO & U.N.E.P. 2020). Habitat degradation is used here in a broad sense to include reductions in habitat quality, species impoverishment, and structural alteration that may precede or accompany habitat loss.

In India, habitat degradation represents a significant conservation challenge because of the high dependence of people on natural ecosystems and increasing anthropogenic pressures. Approximately 300 million people in India are estimated to depend directly on forests and other natural ecosystems for livelihoods, fuelwood, and subsistence needs (Forest Survey of India 2023). In addition, a large number of commercially valuable products, including seeds, bark, resin, fruits, roots, and other non-timber forest products, continue to be extracted from natural habitats. Sustained resource use, coupled with land-use change and development pressures, has contributed to declines in habitat quality and ecological integrity across the landscapes (Davidar et al. 2010).

The impacts of degradation are not restricted to forests. Grasslands and wetlands—historically underrepresented in conservation planning—have undergone extensive transformation and deterioration across India. Grasslands have frequently been classified as 'wastelands,' resulting in large-scale conversion to agriculture, plantations, renewable energy infrastructure, industrial projects, and urban expansion (Vanak et al. 2017; Bharadwaj et al. 2024). Such changes have had severe consequences for grassland-dependent fauna, including the Critically Endangered Great Indian Bustard *Ardeotis nigriceps*. Once distributed widely across the Indian subcontinent, the species now survives in highly fragmented populations, primarily because of habitat loss, degradation, and increasing infrastructure pressures (Bharadwaj et al. 2024). Habitat fragmentation not only reduces the extent of suitable habitat but also isolates populations, restricts dispersal, increases edge effects, and elevates the risk of local extinctions, thereby reducing long-term population viability. Habitat fragmentation, conversion of native grasslands, and associated developments such as roads and power lines continue to threaten the remaining populations of the Great Indian Bustard (Dutta & Jhala 2021). Similar declines have also been reported in other open-habitat specialists, including the Indian Courser *Cursorius coromandelicus* and Great Grey Shrike *Lanius excubitor*, reflecting the widespread degradation of India's grassland ecosystems (SoIB 2023).

Wetlands have similarly undergone extensive degradation across India. Inland and coastal wetlands are increasingly affected by urban expansion, industrial development, pollution, aquaculture, invasive species spread, altered hydrological regimes, and land-use change (Ahmed et al. 2024). Coastal wetlands—including mudflats, estuaries, mangroves, lagoons, and salt marshes—serve as critical habitats for migratory shorebirds and waterbirds using the Central Asian Flyway (Mundkur et al. 2023). However, habitat modification and degradation have reduced the ecological quality of several important coastal sites. Declines and alterations in intertidal habitats across major flyways have been linked to reduced food availability and population declines in migratory shorebirds (Murray et al. 2014; Studds et al. 2017).

The *State of India's Birds* report documented substantial long-term declines among habitat specialist species across India. A steep decline among grassland and woodland specialist birds, compared with generalists has been reported (SoIB 2023). Such patterns suggest that habitat degradation could act as a major driver of biodiversity change and may disproportionately affect species dependent on intact and structurally complex ecosystems.

Research from India has shown that habitat degradation affects bird communities through multiple pathways. Biomass extraction has altered avian communities in tropical dry deciduous forests, thorn forests, Himalayan forests **[136]**, and other ecosystems (Shahabuddin & Kumar 2007; Menon et al. 2019). Selective logging and slash-and-burn cultivation have influenced bird assemblages and ecological interactions in the hills of north-eastern India (Raman 2001; Velho et al. 2012). Similar ecological effects are likely to occur across wetlands and grasslands where habitat alteration changes vegetation structure, resource availability, and ecological processes.

Photo: Ghazala Shahabuddin

136. Forest fragmentation isolates habitat patches and reduces connectivity for birds, as in Nainital, Uttarakhand.

Biological invasions represent another important pathway through which habitats are degraded. Invasive plant species can substantially alter habitat structure and ecological functioning across ecosystems. For example, *Lantana camara* has been shown to affect forest bird communities at both species and guild levels by altering vegetation composition and habitat structure (Aravind et al. 2010). Similarly, *Prosopis juliflora* can modify habitat architecture and negatively influence nesting habitats for birds (Chandrasekaran et al. 2014). In wetlands and grasslands, invasive species can alter ecological conditions and reduce habitat suitability for specialist species.

Across habitats, degradation frequently results in the simplification of vegetation structure, altered microclimatic conditions, and reduced ecological heterogeneity. Studies across Indian forest ecosystems have shown that vegetation structure, canopy cover, and habitat complexity strongly influence bird diversity and community composition (Shahabuddin & Kumar 2007; Menon et al. 2019). Similar patterns have been observed in wetland and grassland ecosystems where habitat structure and ecological conditions influence species assemblages and habitat use (Vanak et al. 2017; SoIB 2023; Ahmed et al. 2024).

Although the drivers of habitat degradation vary among ecosystems, their ecological consequences for birds appear broadly consistent. Multiple studies have documented reductions in species richness, abundance, and community complexity, in degraded habitats relative to more intact systems (Shahabuddin & Kumar 2007; Menon et al. 2019; Barhadiya et al. 2022). Habitat degradation can also alter species composition by disproportionately affecting habitat specialists and functionally important groups such as understory insectivores, frugivores, grassland specialists, and migratory waterbirds. Continued degradation may ultimately lead to ecological homogenization, whereby specialist species are replaced by widespread generalists, reducing ecosystem resilience and conservation value (Newbold et al. 2015; SoIB 2023).

3. Environmental pollutants

The population-level impacts of environmental pollutants on bird species remain poorly documented in India. However, evidence from elsewhere suggests that pesticides and other contaminants can have serious consequences for avian populations (Kuo et al. 2022). The catastrophic decline of Asian *Gyps* vultures caused by toxic veterinary drugs provides one of the clearest examples of how environmental pollutants can trigger rapid and severe biodiversity declines.

The widespread veterinary use of diclofenac in cattle resulted in one of the most severe cases of unintentional secondary poisoning recorded in bird populations anywhere. Between 1992 and 2000, populations of several vulture species declined across India by over 97% (Prakash et al. 2003). India banned veterinary diclofenac in 2006, yet implementation concerns remain, and especially because other non-steroidal anti-inflammatory drugs (NSAIDs), including aceclofenac, ketoprofen, and nimesulide, have also been shown to be lethal to vultures and some eagles (Nambirajan et al. 2021; Chakraborty et al. 2025). Recently, additional bans have been introduced, but their implementation and the removal of these drugs from circulation remain challenging, with some veterinarians even now illegally using diclofenac (Mallord et al. 2025). Another veterinary drug, flunixin, has also been shown to have similar toxic effects (Zorrilla et al. 2014; Fourie et al. 2015). Wild vulture mortalities continue to be recorded despite conservation efforts and the difficulty of detecting this cryptic mortality factor (Chakraborty et al. 2025).

Declines of up to 99.9% in the White-rumped Vulture *Gyps bengalensis* population across India (Prakash et al. 2012) illustrate the scale of the crisis. The persistence of harmful veterinary drugs has so far limited population recovery despite decades of conservation interventions (Galligan et al. 2021; Ghosh-Harihar et al. 2024; Prakash et al. 2024). Vulture losses have also triggered cascading ecological effects, including increased feral dog populations, associated disease risks, greater carcass disposal costs, and documented negative impacts on human health and survival (Markandya et al. 2008; Frank & Sudarshan 2024; Ishwar & Das 2024).

Globally, pesticides are known to affect bird populations through both lethal and sub-lethal pathways. Exposure during reproductive stages can reduce hatching success and fledgling survival while increasing reproductive failure. Effects include suppression of egg formation, eggshell thinning, impaired incubation, and disruption of chick-rearing behaviour (Muralidharan et al. 2004; Rahmani 2012).

Organophosphate pesticides such as chlorpyrifos and carbamates including aldicarb and carbaryl are particularly harmful. These compounds inhibit acetylcholinesterase, with acute poisoning causing substantial enzyme inhibition. Sub-lethal impacts include endocrine disruption, altered feeding behaviour, weakened immune systems, and reduced reproductive success. High accumulation of organochlorine pesticides has also been documented in resident and migratory birds in southern India, largely linked to unintentional poisoning events (Muralidharan et al. 2004; Rahmani 2012).

Heavy metal pollution arising from mining, metal refineries, and thermal power plants is increasingly recognized as a threat to birds, although limited monitoring makes population-level impacts difficult to assess. Evidence from India remains sparse (Jayakumar et al. 2013), and its effects may often go undetected.

Dangerously high concentrations of zinc, nickel, cobalt, chromium, copper, lead, and mercury have been reported in feathers of 15 shorebird species from the Ramsar site of Point Calimere Wildlife Sanctuary and the Pichavaram Mangrove Forest in Tamil Nadu (Anbazhagan et al. 2021). Similarly, concentrations of metals in tissues, feathers, and prey species of birds such as the Indian Pond Heron *Ardeola grayii* and Black-crowned Night Heron *Nycticorax nycticorax* exceeded permissible standards at other sites in Tamil Nadu (Pandiyan et al. 2022). Evidence from Africa also indicates that lead poisoning can substantially affect vulture populations, suggesting that similar risks may remain overlooked in India (Naidoo et al. 2017).

Rodenticides, which are broad-spectrum vertebrate toxicants, are another category of poisons that pose a significant threat to birds through primary and secondary poisoning. Raptors and scavenging bird are primarily exposed by consuming poisoned rodents, whereas non-raptor species may ingest contaminated invertebrates. Large-scale rodenticide applications during agricultural pest outbreaks further increase the risk to migratory birds and raptors by contaminating prey resources across landscapes, resulting in both lethal and sub-lethal effects (Convention on Migratory Species 2014; Vyas 2017). A recent study reported the first documented case of fatal bromadiolone poisoning in an Indian Leopard *Panthera pardus fusca*, emphasizing the broader risks of rodenticides to non-target wildlife (Nambirajan et al. 2026). The long-term consequences of environmental pollutants on birds remain largely unknown because there is no systematic monitoring programme for pollutants across wetlands and other habitats in India. Most of our understanding comes from a limited number of sites and opportunistic investigations following mass mortality events. Occasional bird deaths reported in the media may therefore represent only the visible fraction of a much larger problem, with wider ecological impacts potentially remaining undetected.

4. Urbanization

Urbanization has become a key driver of global land-use change since 1950. The United Nations declared 15 November 2022 as the "Day of Eight Billion" as humanity added another billion individuals to Earth within the previous 11 years. More than half of these eight billion humans live in urban areas. India is one of the top three countries expected to account for 35% of the projected growth of the global urban population between 2018 and 2050.

Urbanization results in the degradation, loss, and fragmentation of natural habitat for birds and exposes them to novel stressors such as elevated pollution levels, increased temperature, and higher densities of free-ranging invasive predators **[137]**. Food subsidies in urban areas can benefit behaviourally dominant species such as the House Crow *Corvus splendens* and Feral Pigeon *Columba livia*, which may crowd out other species over time. Additionally, noise pollution in urban environments can interfere with bird communication, masking mating calls and alarm signals, and ultimately affecting their breeding success and survival (Anthony & Tiwari 2022).

137. Urban expansion often degrades adjoining natural habitats, as in the foothills of the Western Ghats near Coimbatore.

Urban wetlands, despite being among the last remaining natural habitats within cities, continue to support diverse resident and migratory waterbird communities. However, they are increasingly threatened by encroachment, road expansion, sand mining, pollution, hydrological alteration, and other development activities, resulting in significant declines in waterbird abundance and diversity **[138]**. Long-term monitoring of urban wetlands in India has demonstrated rapid declines in waterbird populations, underscoring the importance of protecting and restoring these habitats within urban landscapes (Adhurya et al. 2019; Parameswaran et al. 2023, 2026).

Both photos: Ramesh Kumar Selvaraj

138. Urban expansion around wetlands involves encroachment and hydrological alteration, as in Mumbai, Maharashtra.

Urban green spaces are often dominated by highly manicured exotic ornamental trees, with an impoverished shrub and herb layer. Such limited niches and altered resource availability are likely to affect bird community structure and composition. Several studies have shown that vegetation structural variables such as canopy cover, overall tree and shrub species richness, and vegetation heterogeneity are positively associated with bird species richness in urban landscapes (Khera et al. 2009; Kaushik et al. 2022). Similarly, *Prosopis juliflora* abundance was found to be negatively associated with bird diversity in peri-urban regions of Delhi (Khera et al. 2009). The effects of fragmentation have also been demonstrated (e.g., Tiwary & Urfi 2016). Patch size positively affects bird species richness as reported across multiple studies (Kaushik et al. 2022). Additionally, natural areas in the surrounding matrix can sustain bird populations. Wooded roads and streets can act as corridors by enhancing connectivity between green spaces. Tiwary & Urfi (2016) also highlighted the value of fruiting trees and fruit-bearing avenues, which resulted in higher occupancy probabilities of arboreal frugivorous birds such as Brown-headed Barbet *Psilopogon zeylanicus* and Yellow-footed Green-Pigeon *Treron phoenicopterus* in central Delhi.

Despite these benefits, urbanization studies consistently report homogenization of bird communities due to the increasing abundance of urban exploiters characterized by wide ecological niches. For instance, the Feral Pigeon, Common Myna *Acridotheres tristis*, and House Crow have become more widespread in Indian cities (Tiwary & Urfi 2016; Kaushik et al. 2022).

Introduced pets such as free-ranging cats and dogs affect birds directly through predation and indirectly by creating a "landscape of fear". Globally, studies point towards a substantial, yet underreported bird loss due to free-ranging cats in urban areas (Hong & Mohd-Azlan 2018; Díaz et al. 2022).

Noise and light pollution in urban areas are also significant stressors for birds. Anthropogenic noise can simply reduce the active space for bird songs, compelling individual birds to alter their acoustic characteristics or in the most severe cases, abandon otherwise suitable habitat (Anthony & Tiwari 2022). Artificial light at night also disrupts circadian rhythms, alters activity patterns, and can disorient nocturnally migrating birds, increasing mortality and affecting breeding success (Dominoni et al. 2013).

Urbanization filters out rare and specialist species allowing generalist and common species to flourish. Studies from Kolkata and Amravati reported that urbanized areas had the lowest overall species richness, including fewer rare species, than less urbanized areas (Kale et al. 2018a). Pal et al. (2019) reported a decline in the globally imperilled insectivorous guild with urbanization. Studies from Amravati further showed that urban bird assemblages are nested subsets of rural communities, reflecting the gradual loss of species as urbanization intensifies (Kale et al. 2018b). However, studies from Kolkata and Tiruchirappalli have reported elevated species richness at moderate levels of urbanization (Sengupta et al. 2014; Menon et al. 2016).

5. Energy infrastructure

The issues associated with renewable energy are relatively recent and have been increasing in recent years. India is the fourth largest producer of wind energy with an installed capacity of 39.25 GW as of 31 March 2021 (MNRE 2022). Wind energy contributes about ten percent of total power generation in India and is one of the fastest-growing energy sectors (MNRE 2022). Among the states, Tamil Nadu has the highest installed capacity, followed by Maharashtra, Gujarat, and Rajasthan [139].

Photo: Ramesh Kumar Selvaraj

139. Wind energy infrastructure can pose collision and other risks to birds, particularly when poorly sited.

India's electricity transmission network is one of the largest synchronous interconnected electricity grids in the world with 4,63,758 km of transmission lines and 11,45,107 MVA of transformation capacity as of October 2022 (MNRE 2022). Wind farms are established across the western and southern parts of the country, including key bird-rich habitats such as the Western Ghats and the Gulf of Kachchh, whereas transmission lines extend across the country, often passing through the habitats of endangered species such as the Great Indian Bustard.

Compared to other conventional modes of power generation such as thermal power or large hydro-electric projects, wind energy is considered a form of 'green energy' and is promoted worldwide. However, concerns about their impacts on wildlife, especially birds, have grown over the last two decades (Orloff & Flannery 1992; Drewitt & Langston 2006). Numerous studies have documented bird collisions with wind turbines over the last few decades mainly from Europe and the USA (Hötker 2006; Erickson et al. 2014). This issue first gained widespread attention following the deaths of raptors at the Altamont Pass wind farm in California, USA, during the early 1990s (Orloff & Flannery 1992).

The major impacts of wind turbines on avifauna include: (1) direct collision of birds with the rotating turbine blades, (2) displacement of birds from the turbine areas due to disturbance, and (3) barrier effects, where wind turbines act as barriers to the movement of birds and lead to greater energy expenditure as birds navigate around wind farms (Drewitt & Langston 2006). Studies on the impacts of wind farms on wildlife in India are scarce (Pande et al. 2013; Kumar et al. 2019; Deb et al. 2020). To date, bird collisions have been reported from Gujarat, Maharashtra, Karnataka, and West Bengal. Evidence of bird displacement due to wind farms has been reported in Karnataka, Maharashtra, Rajasthan, and Gujarat (Pande et al. 2013; Thaker et al. 2018; Kumara et al. 2022; Kumar et al. 2022; Roy et al. 2025).

Bird collisions with turbines represent the most direct impact of wind energy infrastructure. Collision risk is influenced by multiple factors and varies considerably among species. Reported mortality rates range from none to 64 birds per turbine per year (Hötker 2006). Although the species affected differ among wind farms, raptors are consistently among the most vulnerable groups (Erickson et al. 2014). For example, the Red Kite *Milvus milvus* and Common Buzzard *Buteo buteo* were the species most frequently affected in Germany (Hötker 2006), whereas Red-tailed Hawk *Buteo jamaicensis* and Griffon Vulture *Gyps fulvus* were among the most frequently affected species in the USA and Spain (de Lucas et al. 2012; Erickson et al. 2014) respectively.

In India, collisions with wind turbines have been documented for a wide range of bird species. In the Samakhiali region of Kachchh, an agricultural wetland matrix, numerous species including waterbirds such as the Painted Stork *Mycteria leucocephala*, Dalmatian Pelican *Pelecanus crispus*, Black-crowned Night Heron, were recorded among the collision victims (Kumar et al. 2019). In the Western Ghats of Karnataka and Maharashtra, recorded species included Bonelli's Eagle *Aquila fasciata,* Changeable Hawk Eagle *Nisaetus cirrhatus,* Black Kite *M. migrans,* Eastern Red-rumped Swallow *Cecropis rufula*, Dusky Crag-Martin *Ptyonoprogne concolor*, Little Swift *Apus affinis*, and Indian Pitta *Pitta brachyura* (Kumar et al. 2019). Across studies from Karnataka, Maharashtra, and Gujarat, raptors were consistently represented among the collision victims, irrespective of habitat type.

The bird assemblage of an area is known to change after the installation of wind turbines there. These changes may persist for years as a result of visual intrusion as well as disturbances such as noise and vibration, which lead to habitat loss (Drewitt & Langston 2006). The displacement of passerines from the wind farms has been documented in the USA and Mexico (Leddy et al. 1999; Pearce-Higgins et al. 2009; Villegas-Patraca et al. 2012; Campedelli et al. 2014). These studies also indicate that many bird species tend to avoid areas close to wind turbines (100–300 m) and this effect is often long-term (Villegas-Patraca et al. 2012; Shaffer & Buhl 2016). Displacement may occur during the construction and operation phases as well. Vehicular traffic and personnel movements associated with turbine-related activities also contribute to the displacement of birds. The extent of displacement can vary depending on the geography, number of turbines, and species involved (Drewitt & Langston 2006). Although song birds are reportedly the most displaced bird group, studies have also found that raptors are displaced from the turbine areas. Garvin et al. (2011) found a reduction in the abundance of raptors after the construction of turbines in Wisconsin, USA.

Within India, field studies have reported lower species richness and diversity in turbine areas, compared to adjacent control sites (Thaker et al. 2018; Kumara et al. 2022; Kumar et al. 2022). Several passerine species showed lower abundance in turbine areas (Kumar et al. 2022). Similar effects on raptors have also been observed, which are thought to cause serious ecological imbalances in these landscapes (Kumar 2017; Thaker et al. 2018). For instance, Thaker et al. (2018) found that wind farms in Karnataka reduced the abundance and activity of raptors, which in turn increased the density of lizards. The long-term impacts of the wind farms on certain groups of birds, particularly raptors, are of greater concern because they produce few offspring and have a long life expectancy. The study by Carrete et al. (2009) demonstrated that wind farms pose a serious threat to long-lived raptors by reducing their survival rates and increasing the likelihood of population decline.

The expansion of wind farms, solar power plants, and other renewable energy technologies has been accompanied by a corresponding expansion of electricity transmission, resulting in an increase in the power line network along with other associated transmission infrastructure. The detrimental effects that power lines and associated structures have on the habitats and biodiversity are well known (Loss et al. 2015; Biasotto & Kindel 2018). Although transmission lines and associated towers can provide resources such as foraging and nesting perches, they also cause bird mortality through electrocution (Biasotto & Kindel 2018). Every year, millions of bird deaths occur due to power line collisions (Loss et al. 2015). Power line mortalities are known to have population-level impacts (Loss et al. 2015) and can even alter migratory patterns (Palacín et al. 2017).

Poorly designed electricity poles and pylons are a major cause of electrocution among large perching birds such as raptors, vultures, and storks, a problem that is less common for smaller birds like passerines. The issue arises because these birds often perch on power lines or pylons, coming into contact with multiple electrical conductors, which can lead to fatal electrocution. Unlike collisions with wires, which can be mitigated through measures such as line markers or rerouting, this threat requires specific solutions such as bird-friendly pylons, insulated conductors, and the placement of bird perches away from dangerous areas.

Although almost 3,00,000 sq. km of India is covered by a power grid network, there is still a lack of research on the effect of overhead transmission and supply lines on birds. Very few focused studies have been conducted on the impacts of power lines on birds (Sundar & Choudhury 2005; Tere & Parasharya 2011; Uddin et al. 2021). However, there are several independent reports of bird collisions in the mass media, such as newspapers (Maxima & Selvaraj 2024).

Power lines affect birds in two ways. For large-bodied bird species, mortality is often due to collision with transmission lines, while electrocution is a major cause of mortality in large perching birds such as raptors, vultures, and storks. Smaller species like passerines are also affected, though electrocution is comparatively less frequently reported and typically occurs on distribution lines under certain conditions. In addition to habitat conversion and fragmentation, overhead power lines can also create barrier effects, leading to collision and electrocution risks for birds (Biasotto & Kindel 2018).

A literature review revealed that more than 70 bird species in India have been reported to be affected by collisions and electrocutions involving power lines (Maxima & Selvaraj 2024). Among these are the Indian Peafowl *Pavo cristatus*, Greater Flamingo *Phoenicopterus roseus*, Sarus Crane *Grus antigone*, House Crow, Indian Roller *Coracias benghalensis*, Himalayan Vulture *Gyps himalayensis*, Lesser Flamingo *Phoeniconaias minor*, and Steppe Eagle *Aquila nipalensis*, which are among the species most frequently reported (Maxima & Selvaraj 2024). Recent studies on vulture populations in India have highlighted that power line collisions and electrocutions are among the leading causes of mortality, further exacerbating the already critical conservation status of these species (Harness et al. 2013; Manigandan et al. 2021; Narwade et al. 2025).

Although bird collisions and electrocutions have been reported across India, mortality reports are particularly numerous in Rajasthan, Haryana, Gujarat, and Uttarakhand. Unlike most other states, Rajasthan has been the focus of several dedicated studies on this issue (Harness et al. 2013; Jhala et al. 2020; Narwade et al. 2021; Uddin et al. 2021). A major concern highlighted by these studies is the impact on the Critically Endangered Great Indian Bustard. At least ten Great Indian Bustards have been killed by power lines since 2017 (Jhala et al. 2020; Narwade et al. 2021; Uddin et al. 2021). The presence of an extensive network of power lines in the species' prime habitats, such as the Jaisalmer District, poses a severe threat to its survival. Another major concern identified by studies from Rajasthan is the high mortality of several raptor species through collisions and electrocutions, including the globally threatened Egyptian Vulture *Neophron percnopterus*, Tawny Eagle *Aquila rapax*, and Steppe Eagle (Harness et al. 2013; Narwade et al. 2021).

While renewable energy is essential for climate change mitigation, its expansion should avoid bird-rich areas, migratory corridors, and habitats of collision-prone species such as the Great Indian Bustard, vultures, and large raptors. Science-based site selection, underground cabling in priority areas, and mitigation measures such as bird diverters and emerging innovations including free-standing flight-path blockers have been proposed to reduce collision risk while supporting sustainable energy development (Uddin et al. 2021; Collar 2025; Narwade et al. 2025). However, the effectiveness of conventional flight diverters in reducing collision risk for bustards is limited (Silva et al. 2023).

6. Climate change

Limiting global heating to the target of keeping warming below 2°C above pre-industrial times, as agreed under the 2015 Paris Agreement, is extremely challenging. Far more likely is a global average temperature rise of roughly 4°C by 2100, accompanied by catastrophic impacts on biodiversity. Apart from the accelerating rise in temperatures itself, extreme weather events such as hurricanes, cyclones, droughts, and floods are expected to occur increasingly frequently and with greater intensity. South Asia is projected to be one of the regions most severely affected by climate change.

Climate change affects birds in several ways. First, phenological mismatches occur when the timing of annual events such as migration, nesting, insect emergence, and plant phenology becomes asynchronous. Second, for sedentary birds, coping with climate change will require long-term in situ evolutionary adaptation over time. For instance, over a fifty-year period, Amazonian bird species showed a decrease in mean body mass, consistent with the idea that warming favours smaller individuals that can dissipate heat more efficiently (Jirinec et al. 2021). Third, higher temperatures can also cause birds to alter their behaviour, making them more likely to seek shade and spend less time foraging, thereby reducing fitness and, in some cases, increasing mortality. Finally, bird species are also shifting their ranges to higher latitudes (away from the tropics and towards the poles) and, in the mountainous regions, to higher elevations.

Deomurari et al. (2023) predict that nearly 70% of bird species in India are likely to shift northwards or upslope under future climate scenarios, with more than half expected to lose portions of their current ranges by 2070. These projected shifts are especially pronounced in mountain systems located in biodiversity hotspots such as the Himalaya and Western Ghats, where major turnover in species richness and community composition is anticipated. A recent assessment integrating climate and land-use projections with population trends projected future habitat loss for 507 Indian bird species, with 121 species already experiencing population declines and projected to undergo further habitat loss, highlighting the urgent need for targeted conservation and monitoring (Diengdoh & Srinivasan 2026).

The suitability of different habitats for birds is often inferred from comparisons of bird communities in disturbed versus undisturbed habitats. However, modern bird communities in undisturbed habitats can be very different from their historic counterparts in the same habitat and location because of climate-driven changes in bird communities that often go undetected. National-scale projections for India suggest that many species will no longer occupy parts of their present ranges even within protected and relatively undisturbed mountain landscapes (Deomurari et al. 2023).

The fitness of all bird populations is dependent on interactions with other species. Such interactions are threatened by both phenological mismatches and by range shifts. Phenological mismatches between predators and prey can drastically reduce individual fitness and reproductive success and may also intensify interspecific competition (Samplonius & Both 2019). When interacting species shift their geographical ranges at different rates, they may occupy non-overlapping ranges, resulting in the loss of ecological interactions between them. Conversely, range shifts can also create novel interactions that may lead to population declines. For instance, many Eastern Himalayan bird species are shifting their elevational ranges upslope in response to climate change, increasing the risk of local extirpation for high-elevation species (Girish & Srinivasan 2022). Similarly, the range expansion of the Indian Peafowl *Pavo cristatus* into parts of Kerala has been linked to changing climatic conditions (Jose & Nameer 2019).

Most terrestrial bird diversity is concentrated in tropical mountains, where species tend to be thermal specialists with narrow temperature niches. The Himalaya is one of the most biodiverse regions for birds globally. As temperatures rise, climate change can cause species' ranges to contract dramatically at mountain summits, leading to local extinctions, especially among high-elevation birds (Freeman et al. 2018). Projections for Indian birds further indicate an increasing concentration of species richness above 2,500 m, alongside severe range losses at lower elevations, suggesting that many high-elevation bird communities will be reshuffled while lowland montane specialists face an increased extinction risk (Deomurari et al. 2023).

Climate change, together with land-use change, is increasingly degrading India's coastal wetlands, with important consequences for migratory waterbirds. A long-term study at the Great Vedaranyam Swamp–Point Calimere complex documented substantial changes in coastal habitats between 1988 and 2017, including a greater than 56% decline in intertidal mudflats, shrinkage of major lagoons, increasing temperatures, and increasingly erratic rainfall patterns. These habitat changes were strongly associated with marked declines in populations of several migratory shorebirds, including Little Stint *Calidris minuta*, Curlew Sandpiper *C. ferruginea*, Tibetan Sand Plover *Anarhynchus atrifrons*, Black-tailed Godwit *Limosa limosa*, and Greater Flamingo *Phoenicopterus roseus*, demonstrating the critical importance of intact mudflat ecosystems for migratory waterbirds (Sathiyaselvam et al. 2019; SoIB 2023). Further studies on the synergistic effects of climate change and habitat loss on birds inhabiting intertidal mudflats, estuaries, and sandbars are urgently needed.

7. Avian diseases

Anthropogenic drivers such as land-use change, intensive livestock production, wildlife trade, and climate change are now known to have indirect effects on the emergence and cross-species transmission of pathogens. Globally, birds harbour a wide diversity of parasites, including those that cause malaria, avian influenza, and West Nile virus. Vector control measures and socio-economic, cultural, and infrastructural changes can, however, help mitigate the effects of such pathogens. In the Indian context, the impact of disease on avian population declines remains poorly understood due to a lack of field-based studies.

Malaria is the deadliest of all vector-borne diseases in India. In 1898, Sir Ronald Ross demonstrated for the first time in Kolkata that mosquitoes could serve as intermediate hosts for bird malaria. He carried out controlled experiments using *Plasmodium relictum* (avian malaria parasites) by infecting *Culex* mosquitoes to demonstrate the complete life cycle and successfully transmitted the parasite through mosquito bites to healthy birds (Ross 1911). Since then, studies using traditional microscopy and molecular methods have provided snapshots of the prevalence and diversity of avian haemosporidians in the Indian subcontinent (Ishtiaq et al. 2007; Gupta et al. 2019; Menzies et al. 2021).

Avian malaria has provided new insights into the ecological epidemiology of blood parasites in South Asia and the South Pacific Islands. With the accidental introduction of the mosquito *Culex quinquefasciatus* and bird species introduced from Africa and India, avian malaria was responsible for the endangerment and extinction of many native Hawaiian birds. Ishtiaq et al. (2007) used populations of the widely distributed Common Myna as a host model. Subsequently, a year-round study in the Himalayan foothills tested the 'enemy release hypothesis' in bird-malaria systems for the first time by comparing the levels of parasitism in resident and migrant birds. The study showed that the tropical climate facilitates the transmission of parasites throughout the year in resident and migrant birds (Ishtiaq 2017).

A range of recent studies has also explored the links between climate change and disease transmission among birds. Global climate change is expanding the distribution of vector-borne pathogens in both space and time, exposing host populations to longer transmission seasons and immunologically naïve populations to newly introduced pathogens. Climate models have predicted that by 2050, high-elevation sites (above 2,600 m) will experience temperatures conducive to malaria transmission (Mozaffer et al. 2022).

Gupta et al. (2019) demonstrated that generalist parasites such as *Plasmodium* can rapidly invade novel communities, while specialists like *Haemoproteus* are less capable of shifting across host species in the Western Ghats. Menzies et al. (2021) explored the effects of feeding location and social behaviour on the presence of generalist and specialist blood-parasite assemblages in the Eaglenest Wildlife Sanctuary, Arunachal Pradesh.

Globally, infectious disease can be a key driver of population dynamics in free-living wild birds as well as in domestic birds. Nearly 7% of globally threatened bird species have declined due to avian malaria (BirdLife International 2022). India is also considered a hotspot for endemic vector-borne diseases. Recently, avian flu outbreaks during 2020-2021 swept through many Indian states causing mass mortality among wild birds (Mongabay India 2021). While these avian flu outbreaks are thought to coincide with the peak migratory season, prompting post-outbreak surveillance and culling, there are also reports of outbreaks in the off-season suggesting endemic transmission within the poultry sector (Mongabay India 2021; Pawar et al. 2023). Some migratory species wintering in India, such as the Bar-headed Goose *Anser indicus* and Brown-headed Gull

Chroicocephalus brunnicephalus, are susceptible to highly pathogenic avian influenza (HPAI) H5N1 viruses. Bar-headed Geese have been reported to be infected during HPAI outbreaks in India, while both species experienced large-scale mortality during the Qinghai Lake H5N1 outbreak, highlighting their susceptibility to the virus and the potential role of migratory waterbirds in virus dissemination along the Central Asian Flyway (Chen et al. 2006; Gilbert et al. 2010).

Yet, the consequences of disease for bird population trends are still poorly known, principally due to a lack of long-term studies. Most studies on avian diseases provide only snapshots of the prevalence and diversity of pathogens. Much more work is required in the Indian context to understand the role of infectious disease in the population dynamics of wild birds. In this context, it is important to track incidents of mass mortality in India and study the disease-causing pathogens and their epidemiology.

8. Illegal killing and trade

Birds are illegally killed for a wide variety of reasons ranging from the capture of live individuals (young, juvenile, or adult) for the pet trade to the collection of their derivatives, including flesh, eggs, feathers, claws, beaks, and casques. Illegal killing may peak during certain seasons when demand for birds or bird products increases. One example is the illegal killing of wintering waterfowl and waders for wild meat consumption. In some cases, birds such as owls and the Indian Roller are targeted because of superstitious beliefs or ritual practices. Birds are also captured in large numbers for the pet trade, pigeon fancying, and the collection of feathers and other body parts for use in fly-fishing, fashion, curios, and amulets.

Illegal killing and trade not only have detrimental effects on species within India but also on species native to other countries. Many of the exotic species illegally traded as pets are either endemic to their native ranges or are listed under various threat categories in the IUCN Red List and protected under the regulated Wild Life (Protection) Amendment Act, 2022, and the CITES Appendices.

India was one of the major exporters of birds (live and dead) to the world: from 1970 to 1980, nearly 14.8 million birds were exported, an average of about 13,45,000 birds per year (Inskipp 1983). At present, there is an overall paucity of information on the effects of illegal killing and illegal trade of bird species.

In 1991, an amendment to the Wild Life (Protection) Act, 1972, listed all bird groups under the schedules of the Act, thereby, prohibiting the hunting, trade, and possession of scheduled species and their derivatives. Since then, numerous anecdotal reports from regions, states, and particular forested areas have indicated the continuing prevalence of illegal killing, illegal trade in bird species, or both. Surveys undertaken in 1997 recorded nearly 250 species, representing approximately 64,500 individuals, being traded illegally in markets across the northern Indian states of Haryana, Punjab, Delhi, Rajasthan, the erstwhile Jammu and Kashmir, and Uttar Pradesh (Ahmed 1997). According to the survey, more than 77% of the trade comprised of the following species: Rose-ringed Parakeet *Psittacula krameri* (26.66%) **[140]**, 'Black-headed Munia' (including both *Lonchura malacca* and *L. atricaplla*) (17.59%), Red Munia *Amandava amandava* (10.80%), Scaly-breasted Munia *L. punctulata* (7.68%), Alexandrine Parakeet *P. eupatria* (7.50%), Plum-headed Parakeet *P. cyanocephala* (4.63%), and Indian Silverbill *Euodice malabarica* (3.09%) (Ahmed 1997).

Photo: Doki Adimallaiah

140. Parakeets are among the species commonly encountered in the bird trade.

In 2020, there was a systematic effort to collate open-source data on traded bird species. The compilation documented 37 seizure incidents of bird species involving bird species across India, of which 23 involved single species and 14 involved multiple species (Mendis et al. 2021). Species subject to illegal killing and trade include parakeets, owls, hornbills, munias, weavers, mynas, bulbuls, vultures, pheasants, francolins, quails, and peafowl.

Illegal killing, in the form of shooting, snaring, or poisoning has a direct effect on avian populations, leading to bird mortality (Aiyadurai 2012; Bhupathy et al. 2013). Nearly all forms of illegal killing are indiscriminate and do not differentiate between the sexes, except when the target is a particular body part. For example, males are preferentially targeted in some species for their casques, hackle feathers, crests, or tail feathers, including the casques of hornbills **[141]**, the hackle feathers of the Grey Junglefowl *Gallus sonneratii*, the crest feathers of the Himalayan Monal *Lophophorus impejanus*, and the tail feathers for the Greater Racket-tailed Drongo *Dicurus paradiseus*, or through the selective trapping of male Red Junglefowl *G. gallus* to invigorate the domestic fowl lineages.


Photo: Satem Longchar

141. Hornbills are targeted in the wildlife trade for their distinctive casques.

Capture and transport of wild birds are often associated with high mortality, with estimates suggesting that between 10% and 90% of captured individuals die before reaching the market (Wyatt et al. 2022). This mortality substantially increases the number of birds removed from wild populations, as additional individuals must be captured to compensate for losses during the trade chain, thereby amplifying the overall impact of illegal harvest on wild bird populations (Wyatt et al. 2022).

Illegal killing and illegal trade of wild birds have been identified as a major threat to many bird species, including Green Munia *Amandava formosa*, Lesser Florican *Sypheotides indicus*, and Blyth's Tragopan *Tragopan blythii*. However, disentangling the synergistic effects of land-use change (habitat loss and alteration) and illegal on individual bird species is difficult and therefore hard to generalise. Nevertheless, there are a few species for which hunting is believed to have played a major role in extinction, such as the Pink-headed Duck *Rhodonessa caryophyllacea* (Ali 1960; Ali & Ripley 1983).

Several threatened species continue to be affected by illegal harvest. The Green Munia, Finn's Weaver *Ploceus megarhynchus*, and Yellow-breasted Bunting *Emberiza aureola* have experienced severe population declines, with trapping for the cage-bird trade identified as a significant threat alongside habitat loss (BirdLife International 2017, 2018a, 2021a). Similarly, illegal killing for subsistence continues to affect species such as the Blyth's Tragopan, while the Lesser Florican and Bengal Florican have historically suffered from hunting in addition to extensive habitat conversion (Kumar et al. 2013; BirdLife International 2018b, 2020, 2021b). The collection of ornamental products, including casques and feathers, has also contributed to the decline and local disappearance of the Rufous-necked Hornbill *Aceros nipalensis* and Great Hornbill *Buceros bicornis* from parts of their historical range (Naniwadekar et al. 2015). Illegal harvest is also a significant threat to waterbirds, with large-scale illegal killing and trapping continuing in several parts of India, including the mass netting of migratory waterbirds in Bihar and the hunting of heronries and wetland birds along the eastern coast of Tamil Nadu (Dey et al. 2014; Ramachandran et al. 2017). Together with habitat degradation, these pressures may substantially affect local and migratory populations, highlighting the need to address both direct exploitation and habitat loss in conservation strategies. The conservation of the Amur Falcon *Falco amurensis* in Nagaland represents a notable success story, where coordinated efforts by local communities, government agencies, and conservation organizations effectively eliminated large-scale illegal killing of the species (Kudalkar & Veríssimo 2024). Hence, these problems have been demonstrated to be tractable in India.

9. Sand mining

The worldwide demand for sand has increased over recent decades (Bendixen et al. 2021). In 2022, the United Nations Environment Programme (UNEP) estimated that 40 to 50 billion tonnes of sand were extracted annually globally. This amount is equivalent to approximately 18 kg per person per day (UNEP 2022). The escalating demand for sand, driven primarily by the construction industry, has led to the widespread extraction of this resource from riverbeds, coastlines, and other sensitive ecosystems, triggering a cascade of ecological consequences that directly and indirectly impact avifauna dependent on these habitats (Torres et al. 2022; Zavaleta et al. 2023). Sand mining activities, often characterized by the removal of vegetation, excavation of sand, and transportation using heavy machinery, can directly destroy habitats, nests, eggs, and young birds, leading to immediate reductions in reproductive success (Gondo et al. 2019). Furthermore, the physical alteration of sandbar morphology can render previously suitable nesting sites inhospitable, forcing birds to seek alternative locations that may be less favourable in terms of food availability, predator protection, or microclimate. The removal of sand can alter the topography, geomorphology, and stability of these habitats, leading to increased erosion and sedimentation (Magoon et al. 2001), altering fish populations and aquatic invertebrate communities, thereby further degrading nesting and feeding sites and reducing their suitability for birds.

Although sand is the second most exploited resource on the planet, following water, the environmental impact of its extraction remains poorly understood (Bendixen et al. 2021). Expanding sand mining operations constitute a growing anthropogenic pressure on riverine and coastal ecosystems, with particularly severe consequences for avian species dependent on sandbars and sandbanks for foraging, roosting, and nesting.

Sand mining in Indian rivers presents a significant ecological challenge, particularly for bird species that rely on sandbars for nesting. Many bird species such as the Indian Skimmer *Rynchops albicollis*, Black-bellied Tern *Sterna acuticauda*, River Tern *S. aurantia*, Little Tern *Sternula albifrons*, Small Pratincole *Glareola lactea*, Oriental Pratincole *G. maldivarum*, and River Lapwing *Vanellus duvaucelii* depend on mid-river sandbars as their primary breeding habitat (Arjun et al. 2023). These mid-river sandbars provide an isolated and predator-free environment that is essential for successful nesting. However, with the rapid growth of the construction industry, the demand for sand has increased dramatically, resulting in widespread extraction of sand from rivers. This extraction poses both direct and indirect threats to nesting birds. Direct impacts including disturbance from machinery and human activity on or near nesting sandbars during the breeding season disturbs birds, which often causes birds to abandon their nests and eggs. Indirectly, the continuous removal of sand disrupts the natural sediment dynamics and river morphology, leading to the degradation or complete loss of these critical habitats.

In India, the National Chambal Sanctuary, a protected area spanning parts of Madhya Pradesh, Rajasthan, and Uttar Pradesh, supports globally significant populations of the globally threatened Indian Skimmer and Black-bellied Tern. In the Chambal region, the discourse around sand mining commonly includes the term "sand mafia." Sand mining has emerged as a serious threat to one of India's finest riverine protected areas, with the potential to severely impact sandbar formation and nesting habitats (Das 2015; Shaikh et al. 2018) **[142]**. Shaikh et al**.** (2018) recorded instances where an active Indian Skimmer nesting sandbar was completely extracted, forcing the birds to abandon the site and search for alternative nesting sites for a second clutch **[143]**. The operation of heavy machinery and increased human presence associated with sand extraction also cause disturbances during critical breeding periods, affecting the incubation and brooding activities. In 2023, sand mining machinery ran over active nesting sandbars, killing all 12 Indian Skimmer nestlings (P. Shaikh *pers. obsv.*).

Despite legal protections, illegal sand mining persists in the National Chambal Sanctuary (Shaikh 2023). Every year, illegal sand mining expands in scale in this region. The large-scale removal of sand from riverbeds alters the sediment deposition processes that are vital for the formation and maintenance of sandbars and sandbanks during each breeding season. In the absence of natural sediment replenishment, existing sandbars shrink or disappear altogether, leaving birds without suitable nesting grounds. Such habitat loss is directly associated with declines in breeding success and population size of sandbar-nesting birds. At several sites, sandbanks and sandbars have disappeared completely. The degradation of sandbars in this area might threaten the reproductive success of birds, potentially leading to long-term population declines (Shaikh 2023). Because many nesting birds exhibit site fidelity to their breeding sites, the disappearance of sandbars may impose additional pressure on them to locate suitable alternative nesting sites.

In 2023, Madhya Pradesh denotified *c.*207 ha of sanctuary land to permit legal sand mining through leased operations. This decision has raised serious concerns among conservationists (Shaikh 2023). Similarly, in the Son Gharial Wildlife Sanctuary, illegal sand mining has been implicated in habitat degradation affecting both reptiles and birds that depend on sandy riverbanks. Intervention by the National Green Tribunal has been necessary to curb these destructive activities (Tiwari 2021).

Sand mining impacts have been recorded in coastal areas as well. Coastal sand mining degrades critical bird habitats by removing nutrient-rich mudflats, increasing salinity intrusion, and reducing benthic prey availability. In the Kadalundi–Vallikkunnu Community Reserve on the Kerala coast, these impacts were identified as major environmental threats contributing to the decline of migratory shorebird populations (Aarif & Prasadan 2014).

Addressing the impacts of sand mining on sandbar-nesting birds is complex, owing to several intertwined challenges. These activities are often unregulated, illegal, and poorly documented. Enforcement of existing regulations remains weak, partly due to limited monitoring capacity and vested economic interests in sand extraction. Furthermore, the demand for sand as an essential construction material provides strong economic incentives that often override conservation priorities, making sustainable management difficult.

142. Sand mining removes riverine sandbars that provide important nesting habitat for birds, as in the National Chambal Sanctuary.

143. Sand extraction can destroy Indian Skimmer nesting colonies, as happened to this colony in the National Chambal Sanctuary.

Both photos: Parveen Shaikh

Priority research and action

Addressing the above challenges requires a more nuanced understanding of their impacts and the implementation of evidence-based mitigation measures. Future research and conservation action must focus on filling critical knowledge gaps and translating scientific evidence into effective conservation strategies.

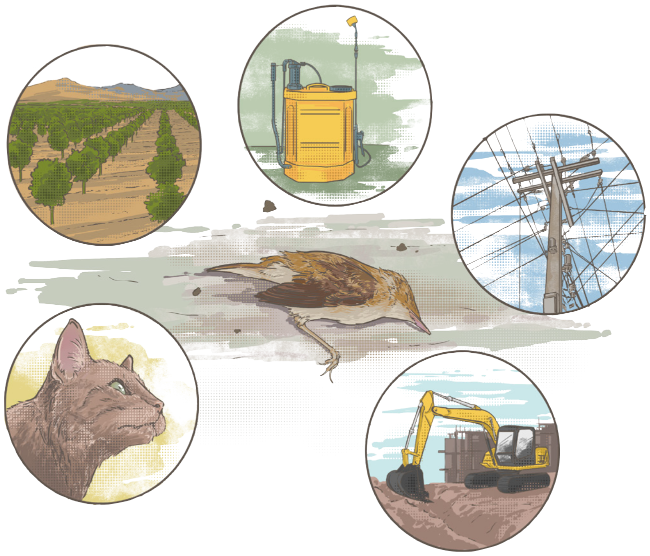
Comprehensive field studies across diverse habitats, robust monitoring frameworks, and adaptive management practices are essential for tackling habitat-specific challenges such as monocultures, urbanization, and habitat degradation. Similarly, the growing menace of environmental pollutants and the impacts of energy infrastructure on birds underscore the need for targeted studies and policy-based interventions. Some key actions required to address these threats are summarized in Table 1.

Conclusions

This review has examined a range of threats to birds in India based on the current peer-reviewed literature. For most threats, the scientific evidence is limited, preventing clear attribution of observed population declines to specific drivers. Moreover, the population size and trend estimates needed for meaningful spatial and temporal comparisons are often unavailable because studies have employed different survey methods. This challenge is compounded by climate change and historical regional population declines that may have preceded systematic

Table 1. Priority research and conservation actions to address threats to Indian birds

Threats	Priority research and conservation actions
Monocultures	• Conduct field studies in a range of monoculture types across different biomes in India to better understand their impacts. • Implement management practices that are now known to mitigate the worst effects of monocultures. • Improve the planning of the conversion of natural habitats to monocultures, including reforestation projects, irrespective of land ownership status (government, private, or community lands), to minimize fragmentation and edge effects.
Habitat degradation	• Conduct research on how localized patterns of degradation translate into regional-scale bird population trends. Incorporating the surrounding landscape matrix into such studies will improve landscape-level planning and management. • Restore habitats on a large scale to stem the decline in habitat specialists, endemics, and endangered birds. • Understand and manage livestock grazing in forests.
Environmental pollutants	• Conduct systematic monitoring of specific environmental pollutants across different habitats to better understand their impacts on bird populations, and use the findings to inform appropriate policy and management. • Investigate avian mass mortality events through qualified laboratories to identify causes and implement measures to prevent recurrence. • Strengthen enforcement of bans on veterinary use of toxic NSAIDs and regulate emerging replacement drugs like flunixin at both national and state levels to facilitate the recovery of vulture populations. • Reduce heavy metal pollution and use of toxic pesticides through improved regulation and the promotion of sustainable agricultural practices such as organic farming and integrated pest management. • Investigate the emerging threat posed by plastic ingestion in birds to quantify its impact and develop effective mitigation strategies. • Strengthen monitoring and enforcement to prevent industrial effluent discharge and dumping of hazardous chemicals into wetlands.
Urbanization	• Conduct long-term studies in smaller towns that are at the forefront of urban expansion to better understand the effects of urbanization. • Incorporate bird-friendly principles into urban planning by safeguarding natural habitats (including terrestrial and wetland habitats) and maximize connectivity through planting of native trees and shrubs in parks, gardens, and along streets. • Adopt bird-friendly building designs to reduce bird mortality from window collisions. • Conduct large-scale research on the effects of artificial light at night on bird behaviour, foraging, and breeding. • Develop and implement best practices for managing urban wetlands to conserve bird diversity and prevent their redevelopment for other purposes.
Energy infrastructure	• Conduct studies on the impact of wind farms and associated power lines on birds in India, given the rapid expansion of such infrastructure. • Establish a national database on bird collisions with power lines and associated mortality. • Use underground cables to mitigate the worst effects of collisions and electrocution, particularly in the prime grassland habitats of endangered species such as the Great Indian Bustard and the Lesser Florican. • Use newly developed sensitivity-mapping tools to guide the siting of new wind farms and minimize their impacts on birds.
Avian diseases	• Expand research on disease ecology, given the increasing prevalence of zoonotic diseases and their exacerbation by climate and land-use change. • Establish year-round surveillance networks to monitor humans, domestic animals, and wildlife within a One Health framework, particularly at sites where large congregations of wild birds occur in the vicinity of poultry farms. • Establish disease surveillance programmes to assess the impacts of climate change on migration and seasonal movements, vector distributions, pathogen emergence, and disease dynamics. • Conduct longitudinal studies of multi-host, multi-pathogen systems to improve understanding of infection dynamics and epidemiological models.
Illegal killing and trade	• Conduct focused studies to quantify the intensity and population-level impacts of illegal killing on targeted species, including waterbirds, owls, parakeets, hill mynas, and pheasants. • Strengthen enforcement and implementation of wildlife protection laws to reduce illegal killing and illegal trade, particularly in light of the increasing number of reported wildlife crime cases. • Engage local communities while implementing existing laws to better understand the drivers of illegal killing, including subsistence needs and income generation, and develop appropriate alternatives where necessary. • Reduce demand for illegally traded birds through public awareness and behaviour-change initiatives, particularly among pet owners.
Climate change	• Assess how climate-driven range shifts alter species interactions, identify interactions that may be lost or newly formed, and evaluate the consequences for ecosystem functioning and bird conservation. • Strengthen habitat connectivity across landscapes and flyways to facilitate species movements, and integrate climate adaptation into land-use planning, protected area management, and national and international conservation policies.
Sand mining	• Identify, map, and monitor key sandbar-nesting sites using satellite and ground surveys to track habitat changes resulting from sand mining. • Assess the ecological impacts of riverine and coastal sand mining on bird breeding success, habitat quality, prey availability, and geomorphological processes to guide conservation and habitat restoration. • Strengthen enforcement of riverine and coastal sand mining regulations, restore degraded sandbars, beaches, and mudflats, and engage local communities in habitat protection and monitoring.



monitoring. Together, these factors constrain a comprehensive understanding of human impacts on bird populations.

In a megadiversity country like India that is undergoing rapid development, systematic research is needed not only across broad spatial scales but also on specific threats at the local scale. At the same time, initiatives such as the *State of India's Birds*, which synthesize and assess large-scale citizen science datasets, provide an effective means of identifying species declines and detecting emerging threats before they become widespread. Such assessments can help identify bird species and other taxa of conservation concern, thereby guiding targeted research to determine the drivers of decline or increase and inform timely conservation action.

The available evidence provides stronger support for cause-and-effect relationships for threats affecting habitats, particularly habitat loss, habitat degradation, and mining. Habitat loss resulting from urbanization, monocultures, infrastructure development, and over-exploitation has had a considerable impact on Indian bird populations over the past few decades. Among these threats, the effects of forest degradation and tree monocultures are relatively well studied in India. In contrast, other threatened ecosystems, including deserts, grasslands, and marine and coastal ecosystems, remain poorly studied. Existing studies from the Himalaya also provide compelling evidence that climate change is already affecting bird populations at the population level.

Our review points to an urgent need to protect the remaining natural habitats through better land-use planning and regulation of new infrastructure development. India is witnessing a rapid expansion of infrastructure projects, including highways, dams, railways, and industrial developments, yet their impacts on bird populations remain poorly understood and rarely monitored. Our review also demonstrates that even relatively small-scale infrastructure, such as wind energy developments, can have considerable impacts on bird populations despite often being regarded as 'green' infrastructure.

The population-level effects of environmental pollutants and avian diseases remain poorly understood because of inadequate research. However, several mass mortality events during the last decade suggest that avian pathogens and pollutants may be more widespread than previously recognized. These findings highlight the need for increased vigilance, systematic monitoring, and targeted research to better understand their long-term consequences for bird populations.

At the same time, much more research is needed in production landscapes such as urban areas, logged forests, fishing zones, and agricultural landscapes. While there is considerable evidence that agricultural intensification and urbanization have reduced bird diversity, relatively few studies have explored how the conservation value of these production landscapes can be enhanced. Production landscapes managed with biodiversity in mind can help mitigate the effects of habitat fragmentation and climate change while providing additional habitat for many species.

It is important to note that our review does not explicitly consider the synergistic effects of the different threats discussed. For instance, habitat loss is likely to interact with environmental pollutants, disease, climate change, and illegal killing to affect bird populations more severely than would be expected from any single threat acting alone. Our conclusions are therefore likely to be conservative. Based on our review, precautionary action is required at multiple levels, rather than relying solely on narrowly targeted responses to individual threats or species. Addressing these challenges will require coordinated action by researchers, policymakers, conservation practitioners, and civil society to ensure that India's remarkable bird diversity is conserved for future generations.

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