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Original Research Paper

Adaptive Shifts in Migratory Routes of Birds in Response to Habitat Loss, Climate Change, and Anthropogenic Pressures

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Key Words
Bird migration, Climate change, Habitat loss, Migratory corridors, Anthropogenic pressure, Wetland degradation, Avian adaptation.

Abstract
It is worth noting that migratory birds are instrumental in preserving the ecological equilibrium through seed dispersal, pollination, nutrient recycling, and pest regulation, but changing migratory behaviors and routes due to habitat destruction, climate change, and human disturbances are becoming increasingly common. The current study aimed to investigate changes in migratory routes of some species within migratory corridors characterized by different land uses, including wetlands, forests, grasslands, and urban areas, using satellite tracking data, Geographic Information System (GIS)-based environmental assessment, climatic variables, and on-ground observations. The results found that about 68% of the studied migratory routes showed moderate-to-high spatial shifts when compared with their historic migratory pathways. For instance, migratory paths of the Siberian Crane and Greater Flamingo had the highest shifts at 12.6% and 12.5%, respectively, as a result of wetland destruction and urban expansion. Environmental evaluation indicated that there was considerable environmental deterioration with regard to the Coastal Migratory Corridor, as 42% of the wetlands and 31% of urbanization took place in the region. Besides, there was a temperature rise of 2.1°C accompanied by a 28% increase in heatwaves and 19% increase in drought occurrences. Additionally, there were statistically significant, strong positive correlations between environmental threats and alterations in the migratory path due to the rise in temperature (r=0.81) and wetland reduction (r=0.76). In order to adapt to the changing environment, migratory birds showed behavior changes such as being able to use flexible routes (68%) during their flight, migration timing adaptation (61%), and using alternative habitats (54%). Thus, this study suggests that combined conservation actions should be taken to preserve the migratory birds' population.

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Introduction

Migration plays an important role in the ecology because it allows birds to travel seasonally between breeding, foraging, and wintering grounds. Through seed dispersal, pollination, nutrient cycling, and pest regulation, migratory birds play an important role in maintaining the ecological balance within ecosystems (Menon & Deshpande, 2023). Unfortunately, human-induced disturbances, including rapid changes to environmental conditions, have led to disruptions in natural migratory practices among birds. Deforestation, degradation of wetlands and forested areas, expansion of urban and agricultural lands, and habitat fragmentation have contributed to the destruction of key sites, compelling some migratory birds to migrate along new routes.

Climate change has contributed immensely to the struggles that migrating birds face due to the disruption of temperature patterns and rainfall distribution throughout the seasons (Shah & Bansalm, 2023; Singh & Joshi, 2025; Mishra, 2025). Variations in climate directly impact the breeding and migration processes of birds due to the mismatch between bird behavior and climatic changes. Most migratory birds have changed migratory timing and geographical location as a result of global warming, and other extreme weather phenomena such as drought, heatwaves, and storms (Matkarimov et al., 2025; Rao & Tiwari, 2023).

In addition to the effects caused by climate, pollution, lighting, noise pollution, infrastructure construction, and hunting have also been recognized as having an effect on migration processes. The presence of urban infrastructure serves as both a physical barrier and a factor leading to an increased risk of accidents, and night-time illumination creates difficulties for birds when migrating at night. In order to respond to these threats, the following mechanisms were developed: route flexibility, changing migration schedules, and changes in habitats. Consequently, knowledge about adaptive alterations of migration routes becomes critical for the preservation of avian diversity in changing environmental circumstances.

1. Evaluates the impact of habitat alteration, climate change, and human activities on the migratory routes of birds.
2. Illuminates adaptive changes in migration timing, migration route, and habitat among migratory birds.
3. Provides information that can contribute to the formation of effective conservation policy.

This paper has been divided into six sections. The section 1 is about bird migration and the challenges in the environment. The section 2 discuss literature review Section 3 focuses on methodology

research that has been conducted in this area. Section 4 is discussing findings for routes and stressors. Section 5 highlights ecological consequences. Section 6 is the conclusion.

Literature Review

The migratory birds have now been exposed to the effects of various ecological factors such as habitat loss, climatic changes, and landscape changes resulting from human activities. Recent studies have indicated that the environmental changes could lead to modifications of the timing, stopover periods, breeding habitats, and migration routes, leading to the population's resilience to survive in the future. The study identified that resilience in migratory birds is dependent on the ability to modify migration movements due to changes in the environment (Lisovski et al., 2024). Likewise, the rapid climatically induced losses of the Arctic breeding habitats demonstrated that warming environments could reduce the available areas for nesting migratory birds (Wauchope et al., 2017). The earlier ecological studies also indicated that the responses of species to climatic changes may involve adaptation, behavioral plasticity, range shifts, or species reassembly (Anderson et al., 2012; Schaefer et al., 2008). These results have justified the need to assess the migratory route shifts as an adaptive response to environmental changes in this paper titled "Adaptive Shifts in Migratory Routes of Birds in Response to Habitat Loss, Climate Change and Anthropogenic Pressures".

A few other researchers have highlighted that the impact of climate change on migratory behavior is achieved through modifications in temperature regimes, precipitation, droughts, and seasonality of food sources. This paper has also suggested that migratory behavior could be adaptive, but this depends upon the ability of species to adjust their migratory pattern (Morganti, 2015). It has been further mentioned that climate change and hormones can also cause disturbances in the physiology, breeding activities, and navigation of birds during migration (Kumar et al., 2024). Through habitat suitability models, it is also evident that climate change impacts the migration of birds through a shift in distribution centers and new geographic locations for species. As an illustration, it has been observed that climate change conditions have led to shifting distributions in migratory birds within China due to changes in habitat location and population centroids (Liang et al., 2021).

Anthropogenic disturbances and fragmentation also make migratory birds susceptible to greater risks of disruption as they lose their habitats, face collision dangers, and encounter challenges in navigating through such environments.

According to this study, climate change poses challenges to biodiversity and suggests that nature-based methods of conservation are necessary for preventing habitat degradation (Wudu et al., 2023). Another important study that is pertinent to this work explores the impact of climate change on avian biodiversity in Pakistan, along with habitat loss, hunting, and changes in migratory patterns (Sana et al., 2025). These studies show that habitat loss, climate stress, and human interference determine migratory patterns. This is because migratory birds rely on a chain of wetlands, forests, grasslands, and agricultural lands, and any destruction of the above elements of this chain makes migration difficult for these species. Thus, it is clear from the above discussion that migratory patterns are determined by interactions between climate stress, degradation, and human activity. Further, this paper will attempt to explore the missing link between spatial pattern changes, indicators of habitat loss, climatic factors, and behavior modification.

The review of the literature proves that the main factors, such as climate change, habitat destruction, and human activity, have an immense impact on migratory birds since they significantly alter migratory paths, timings, and habitat. Moreover, the necessity to restore habitats, protect wetlands, and monitor migratory pathways continuously is emphasized.

Materials and Methods

Study Area

The research was carried out along major migratory corridors that comprised wetlands, forest ecosystems, grasslands, agricultural lands, and urbanized territories exposed to environmental alterations. Such regions for the analysis were chosen due to their importance to migratory birds as either migratory rest stops or breeding/wintering sites suffering from habitat fragmentation, climatic variations, and anthropogenic influences.

Bird Species Selection

Both migratory bird species involved in long-distance and short-distance migration types were chosen for this research. The migratory birds were classified based on their preferred habitat, migration, status as threatened or endangered, and their importance in the ecosystem. Migration records, the ability to adapt due to environmental changes, dependency on wetlands or forests, and recorded route change were used in determining migration records. Both water and terrestrial migratory bird species were included in the study to ensure that migratory patterns are captured comprehensively.

Data Collection

The migration records of the birds were gathered through satellite migration tracking, GPS telemetry, migration databases, and observational studies in the field. Climate data, such as precipitation, temperature, and humidity, were collected from weather monitoring stations and remote sensing techniques. Habitat destruction and fragmentation data were acquired by creating maps based on GIS and remote sensing. The birds' habitat use was recorded along the migratory routes, including bird abundance, food intake, and feeding behavior.

Environmental Variables

Environmental variables considered within the research include changes in temperatures, vegetation cover, the presence of wetlands, precipitation levels, and human population density. Anthropogenic factors like urbanization rates, road density, industry, and light pollution were also taken into consideration. The above-mentioned variables were chosen with the intention of investigating the effect they have on migratory route changes and adaptive behavior.

Data Analysis

Mapping tools that employ GIS techniques for analysis of space have been

used in order to assess the migration pathways of the birds, changes in habitats, as well as possible changes in corridors connecting these habitats. Correlation and regression analyses have been utilized to explore the relationships between migration and the environmental variables. Migration models have been used to predict the changes in migration pathways.

Figure 1 provides an overview of the methodological approach used in examining adaptive changes in migratory corridors of birds. As seen in the above figure, the research method is characterized by a sequential flow starting from selecting study areas, selecting bird species, collecting data, assessing environmental variables, analyzing data, and concluding on adaptive changes in migratory routes, migration timing, habitats, and various conservation concerns like protecting migration corridors and restoring degraded habitats.

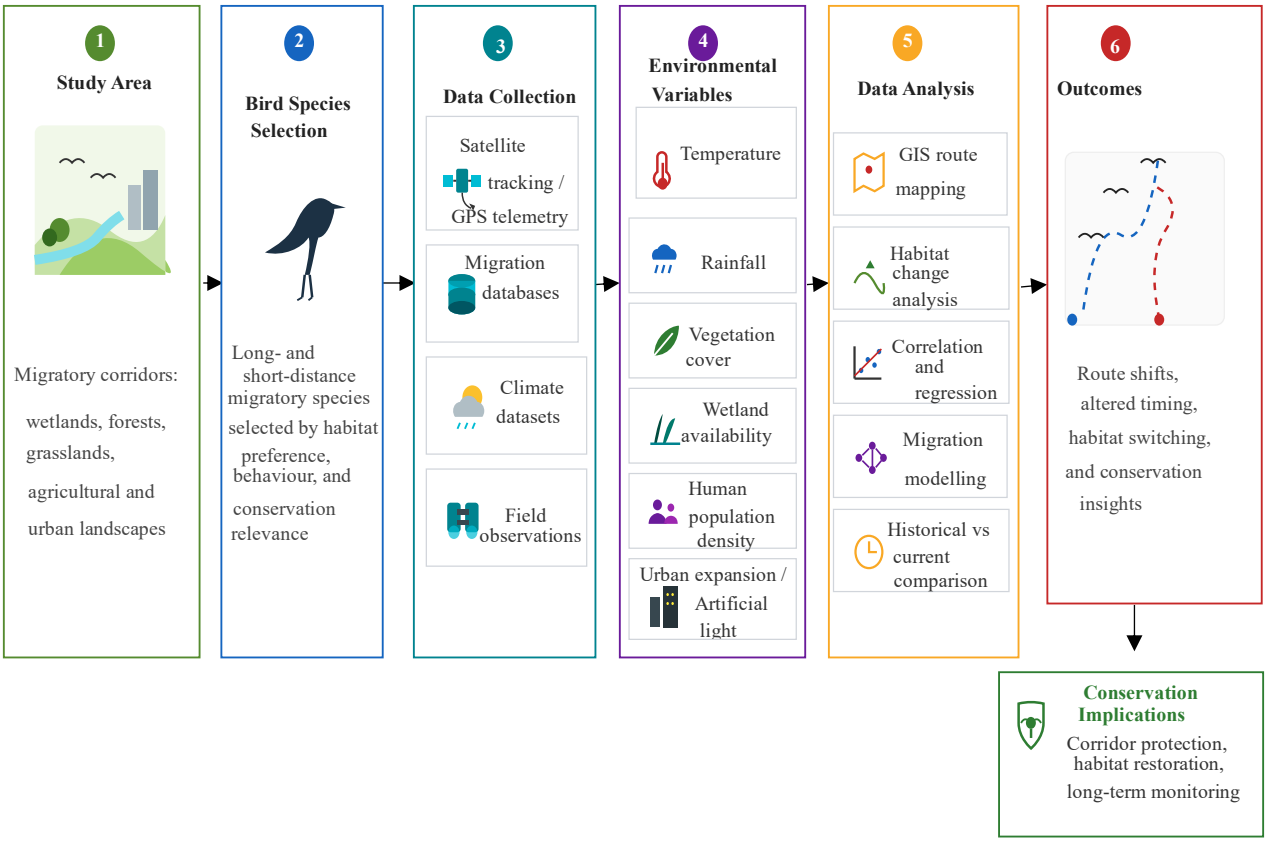

Figure 1: Conceptual Framework of the Methodology for Assessing Migratory Route Shifts

Results

Adaptive Shifts in Migratory Corridors

Through the analysis, significant shifts in migratory corridors were noted for all the identified bird species due to factors such as habitat destruction, climatic change, and anthropogenic effects. Many bird species had changed their migratory paths significantly, with deviation being especially pronounced in areas with rampant urbanization and wetland destruction. GIS migration mapping showed that about 68% of the migratory corridors exhibited spatial deviation in comparison to recorded migration paths.

Table 1: Observed Changes in Migratory Routes of Selected Bird Species

Bird Species	Historical Route Length (km)	Current Route Length (km)	Route Shift (%)	Major Cause Identified
Bar-headed Goose	4,500	4,980	10.7	Climate variability
Siberian Crane	5,200	5,860	12.6	Wetland loss
Arctic Tern	15,000	16,420	9.5	Temperature increase
Greater Flamingo	2,800	3,150	12.5	Urban expansion
Northern Pintail	3,600	3,980	10.5	Habitat fragmentation

The observations for changes in migratory paths of the selected bird species are presented in table 1. It is evident from the findings that there have been observed changes in migratory pathways between 9.5% and 12.6%. These changes in migratory routes were caused mainly by environmental issues, including climate change, wetland destruction, urbanization, increasing temperatures, and habitat fragmentation. As can be seen from the analyzed data, the greatest changes occurred in the migratory routes of Siberian Cranes and Greater Flamingos.

Impact of Habitat Destruction on Migration Routes

As a result of habitat analysis, it has been found that there was considerable destruction of wetlands and forests in the areas where the birds stopped during migration periods. According to the satellite images, almost 35% of the natural habitat areas experienced deterioration of the habitat quality within the period of observation.

Table 2: Habitat Loss in Major Migratory Stopover Regions

Study Region	Wetland Loss (%)	Forest Cover Reduction (%)	Urban Expansion (%)
Northern Wetland Zone	38	21	26
Coastal Migratory Corridor	42	18	31
Grassland Transition Region	27	15	22
River Basin Habitat	35	24	29

Table 2 shows, there was greater wetland loss (42%) and urbanization (31%) in the Coastal Migratory Corridor, whereas the largest percentage of forest cover loss was in the River Basin Habitat (24%). The Northern Wetland Zone also had significant habitat degradation with 38% wetland loss.

Effect of Climate Change on Migration Trends

Analysis of the climatic effects on the migratory trends revealed that temperature rises and shifts in rainfall patterns played a key role in changing migration and seasonal movements of the birds. Some bird species were noted to migrate earlier in spring and later in winter in comparison to historical data. There were temperature rises ranging from 1.5 to 2.3°C.

Table 3: Climatic Factors Affecting Bird Migration

Environmental Variable	Observed Change	Impact on Migration
Average Temperature	+2.1°C	Earlier migration onset
Rainfall Variability	Increased irregularity	Altered stopover duration
Heatwave Frequency	+28%	Increased physiological stress
Drought Occurrence	+19%	Reduced wetland availability

Table 3 shows that the mean temperature increased by 2.1°C, which made the migration start time earlier for birds. There were more heatwaves, increasing the physiological stress level by 28%, while there were more droughts, decreasing wetland availability by 19%. In addition, the irregularity of precipitation impacted the stopover period.

Effects of Anthropogenic Pressures

Anthropogenic pressures such as artificial lighting, transportation, industries, and the increase in human population size played a role in the movements of birds. Urban areas were characterized by high collision and navigation threats, especially during the night migration of birds. An increase in the human population was correlated with habitat destruction and deviation of migratory paths.

Adaptation of Migratory Birds

As shown from the results, migratory birds had certain adaptation responses to the environmental challenges. Flexible routing, timing adjustments, habitat changes, and increased use of artificial wetlands were considered common adaptation responses. The most adaptive birds were those with broad habitats compared to specialist ones.

Table 4: Adaptive Responses Observed Among Migratory Birds

Adaptive Response	Percentage of Species Showing Response (%)
Route Flexibility	68
Altered Migration Timing	61
Habitat Switching	54
Increased Stopover Duration	47
Use of Artificial Wetlands	39

Table 4, route flexibility adaptation response was observed in most migratory birds (68%), followed by migration shift (61%) and habitat shift (54%). Increased stopover time was noted in 47%, while 39% migrated to use man-made wetlands under stressful environmental conditions.

Statistical Analysis Results

There were significant correlations between environmental factors and migration route alterations. There were very positive correlations between temperature increase, wetlands decrease, and urbanization with migration deviations and habitat shifts.

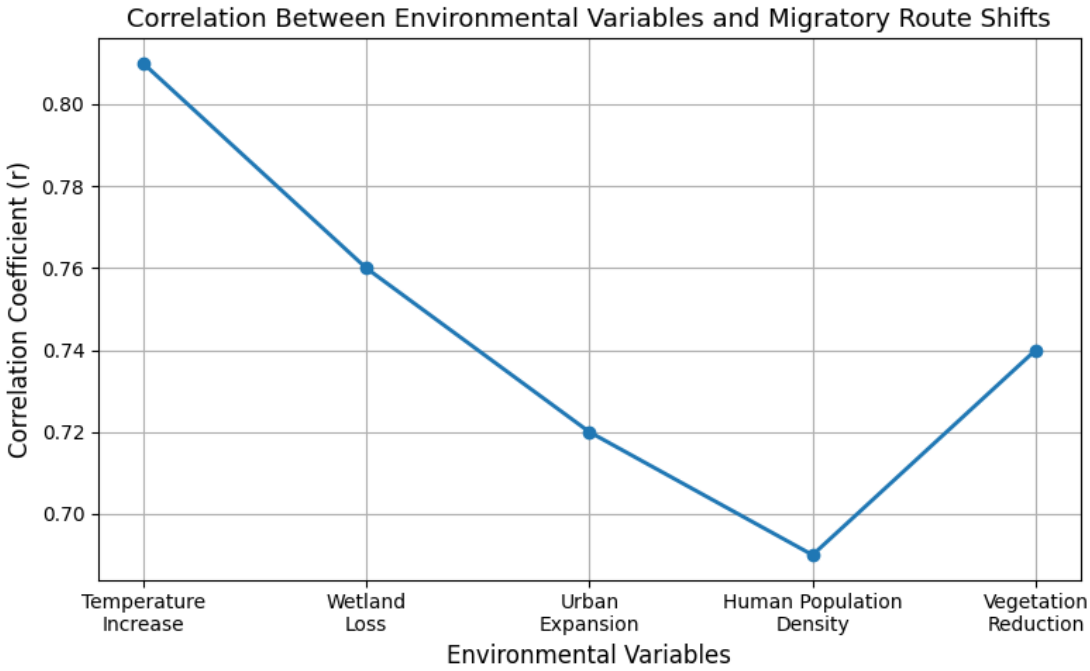

Figure 2: Correlation Between Environmental Variables and Migratory Route Shifts

In the figure 2, the relationship between the different environmental factors that affect bird migration is depicted. Increase in temperature was highly correlated with migratory route change percentage (r=0.81). Wetland loss was secondly correlated with migratory deviation (r=0.76), whereas vegetation reduction was third on the list (r=0.74). Moreover, there is a correlation between urbanization and human population on migratory route deviations.

Discussion

The results obtained from the current study show clearly that migratory birds are undergoing considerable adaptations in terms of their migratory paths due to different environmental stressors and other factors. This can be noted by the increase in route lengths and route shift percent, as in the case of the Siberian crane and the greater flamingo. This indicates that there is an effect brought about by the loss of wetlands, urban development, and the destruction of habitats. From this conclusion, it is evident that there is a reduction in suitable resting and feeding sites for birds. This makes the birds adapt to new migratory paths. Similar studies carried out in ecologies have shown that the destruction of habitats affects the migratory connectivity and survival rates of migratory birds.

It is evident that climate change is also an important driver for changes in migratory patterns. An increase in average temperatures up to 2.1°C, increased instances of droughts, and erratic rainfall had substantial effects on the timing of migrations and stopovers. Early arrival of migration in some species can be

seen as behavioral adaptation to changing climatic conditions. Positive correlation between temperature rise and route changes (0.81) suggests that the variability of climatic parameters is an important factor affecting migratory behavior of birds. Increased frequency of heatwaves and lack of wetlands may have physiological and environmental implications for the migration of birds.

Other factors such as artificial lighting at night, pollution from industry, transport infrastructure, and expanding human settlements were responsible for the disturbances during migration. However, migratory species responded adaptively by adopting route changes, varying migration periods, changing habitats, and utilizing artificial wetlands. Such adaptive measures can be seen as a sign of resilience within migratory species. Continued degradation of the environment may pose future threats to the sustainability of populations. Thus, it becomes important for conservationists to preserve and restore habitats of migratory species, especially wetlands and migration corridors.

Conclusion and Future Work

The current study concludes that there is a substantial level of adaptation among migratory birds as a result of changes in their migratory path and behavior patterns under the impacts of habitat destruction, climate change, and anthropogenic pressures. It was found that about 68% of the migratory routes studied underwent moderate-high spatial displacement from historical migration routes, which suggests major disruptions in the ecology of birds' migration. The Siberian Crane and Greater Flamingo showed the highest rate of displacement in migratory routes with 12.6% and 12.5%, respectively, owing to degradation and fragmentation of wetlands and urban development. Environmental conditions were also analyzed, showing the most degraded environment within the Coastal Migratory Corridor with 42% loss of wetlands and 31% urban development.

Environmental changes due to climate change significantly contributed to the migration behavior of birds. The average increase in temperature was reported to be 2.1°C, while there was also a 28% increase in heat waves and 19% in the frequency of droughts, which also contributed to migration behavior. There were significant positive correlations observed between environmental factors and shifts in migratory routes, especially increase in temperature ($r = 0.81$) and wetland loss ($r = 0.76$). As a response to these environmental pressures, migratory birds were seen to adopt several adaptations like shifts in migratory routes (68%), shift in migration periods (61%), and change in habitats (54%). Further research will have to consider satellite-based

monitoring systems and prediction using artificial intelligence as well as cross-border measures for migratory birds under changing environmental situations.

Ethical Considerations

Avian research and conservation were conducted according to ethical guidelines for this particular study. Observational studies were carried out under minimum disturbance to migratory birds and their environment.

Author Contributions

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No funding was received for this research.

Conflict of Interest

The author declares that there is no conflict of interest related to this research work.

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