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Assessing the Impact of Climate Variability on Migratory Bird Patterns and Habitat Dynamics: A Case Study of Bharatpur, India

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ABSTRACT

Climate change, largely driven by the rapid rise in greenhouse gas emissions, is now widely recognized as a major force reshaping ecological systems around the world. One of the clearest signs of this transformation is the noticeable shift in bird migration patterns, particularly among species that travel long distances. This study explores how unusual changes in temperature and rainfall are influencing migratory bird behavior in Bharatpur, a renowned wetland region in India. Using a combination of firsthand insights from local communities and sanctuary staff, along with official climate data from the Indian Meteorological Department (IMD), the research follows a mixed-method approach. Fieldwork, ecological monitoring, and statistical analysis were conducted to better understand these dynamics. The results show a clear decline in the arrival of iconic species, such as the Indian Sarus and the Siberian Crane, which is linked to irregular rainfall and

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warmer winters. Changes in seasonal timing, such as earlier blooming of plants and insect emergence, are also creating mismatches with bird breeding periods, resulting in food shortages for chicks. The study also notes that while monsoon rains tend to support crane populations, excessive winter rainfall may have the opposite effect. In addition to climate pressures, human-related challenges such as shrinking habitats and the spread of invasive species are further endangering these migratory birds.

Keywords: Climate Variability; Bird Migration; Bharatpur Bird Sanctuary; Rainfall trend

1. Introduction

Climate variability is largely driven by the growing concentration of greenhouse gases, particularly carbon dioxide, in the Earth's atmosphere. Prior to the onset of industrialization, atmospheric CO₂ levels were around 280 parts per million (ppm). Since then, they have risen sharply by roughly 49% reaching approximately 419 ppm in 2023^[1]. This concentration is believed to be higher than at any point in the past 800,000 years and possibly exceeds levels observed in the last 20 million years. What makes this trend especially concerning is not just the increase itself, but the speed at which it is occurring^[2]. Current rates of atmospheric carbon accumulation are estimated to be at least 100 times faster than historical averages over the past 600,000 years, potentially representing one of the most rapid shifts in Earth's climatic history. These elevated greenhouse gas levels have contributed to a global temperature rise of approximately 1.3 °C over the past hundred years^[3], with two-thirds of that warming occurring in just the past quarter-century. During this period, temperatures have been climbing at an accelerated rate of about 0.3 to 0.4 °C per decade^[4]. Projections suggest that if current trends persist, global temperatures may rise by more than 2 °C before the century ends.

One of the most immediate effects of global warming is the increase in average temperatures across different parts of the world. In arid zones, such as the southwestern United States, this warming is expected to result in longer drought periods and an increased frequency of wildfires. Meanwhile, tropical areas are likely to experience more intense and frequent hurricanes, leading to widespread flooding and wind-related destruction^[5]. Rising global temperatures also contribute to the melting of glaciers, which in turn raises sea levels, posing a threat to coastlines through erosion and habitat loss. In addition to warming, the oceans are absorbing greater amounts of atmospheric carbon dioxide, leading

to a steady increase in ocean acidity. This dual impact, rising temperatures and acidification, is likely to significantly alter marine and coastal ecosystems. These environmental shifts have far-reaching implications for bird species, many of which depend on stable habitats for breeding, feeding, and migration^[6]. Therefore, understanding the broader changes occurring in Earth's climate system is a necessary foundation for evaluating how birds may be affected by climate variability. It is essential to comprehend how the distribution of a species can change with a shifting climate in order to protect biodiversity and develop sound policies^[7].

Global warming has been observed to significantly alter the migratory patterns and timing of many bird species across different regions of the world. Since 1970, the worldwide number of migratory birds has decreased substantially. The principal factor behind the abundance decline is that climate change increases the survival stress of migratory birds, which will lead to an ecological crisis and non-ecological function^[8,9]. Rising temperatures have led several migratory birds to adjust their traditional routes, with some shortening their journeys, change direction, or even abandon migration altogether^[10,11]. For instance, a growing number of small bird species that once spent winters in Spain, France, or northern Africa are now choosing to remain in the milder climates of the United Kingdom, where they also breed^[12]. Similarly, cranes that previously migrated to the Iberian Peninsula are increasingly staying in Germany, often alongside starlings. However, this shift in behavior comes with serious consequences. These species are generally not adapted to survive harsh winter conditions, and a sudden drop in temperature can lead to high mortality rates among populations that would otherwise have sought warmer climates^[13].

Rising spring temperatures in many regions have caused migratory birds to arrive at their breeding grounds earlier than they did in previous decades. In the United Kingdom, for example, some bird species now reach their nesting

areas two to three weeks earlier compared to thirty years ago^[14]. This change causes the breeding season to start earlier. At the same time, warmer conditions also prompt earlier blooming of plants and premature insect emergence. However, these changes are not always synchronized. The peak of vegetation growth and insect availability often occurs before the chicks hatch, creating a timing mismatch. As a result, adult birds may struggle to find adequate food for their young during the most critical stages of development^[15].

Throughout Earth's long history, climate has continuously shifted, and species have either adapted, evolved, or disappeared in response to these changes. While climate variability itself is not a new phenomenon, many species in the past failed to cope with such transformations, leading to altered life cycles or extinction^[16]. The same natural cycle applies today, as bird species capable of adjusting to rapid environmental changes may continue to survive, albeit with noticeable modifications to their behaviors and ecological roles. However, what distinguishes the current phase of climate variability from earlier epochs is its intensity and human-driven origin. The speed at which these changes are occurring, largely due to anthropogenic influences, is putting significant pressure on both large and small species to adapt quickly. For many birds, this accelerated pace of change, combined with threats like habitat destruction, pollution, and invasive species, poses serious challenges to survival^[17]. In addition to climate-related stressors, remaining natural habitats are increasingly at risk due to fragmentation, land-use conversion, and overdevelopment, further compounding the threat to biodiversity.

In addition to climate-related challenges, many migratory bird species face obstacles such as wind turbines and increased competition from invasive species. These pressures further weaken populations that are already struggling to adapt. When combined with the broader impacts of climate variability, these factors significantly increase the risk of habitat loss and extinction. For some species that are already on the brink, climate change may act as the tipping point, accelerating their decline and potentially pushing them toward extinction^[18].

Among various bird species, long-distance migratory birds are particularly vulnerable to the effects of climate change. Due to their reliance on multiple ecosystems across continents and their relatively low flexibility in behavior,

they are often the most severely impacted. Research and observational studies suggest that climate change influences bird populations in a variety of ways, affecting everything from distribution and abundance to behavior, migration patterns, and even genetic traits^[19]. Like many other organisms that rely heavily on environmental cues such as temperature and rainfall, birds are highly sensitive to shifting climate conditions. Rising temperatures and reduced precipitation can disrupt their life cycles, while also increasing exposure to competitors, predators, parasites, diseases, and extreme weather events such as storms and wildfires in breeding areas^[20]. A correlation has been found between extreme events and altered migration patterns, but there is a lack of predictive models to address future impacts. Future studies should focus on developing and employing predictive models to better prepare for these impacts^[21]. This study outlines some of the key impacts of climate variability on migratory birds that have been documented around the world.

The study aims to identify how climate change is impacting the migration patterns of birds. Climate change is one of the biggest challenges facing our planet, with implications for ecosystems and wildlife. Birds are particularly attuned to environmental conditions related to climate change, as their survival and reproduction depend on specific conditions. Several research studies have reviewed how climate change is modifying the distribution of birds in India. The findings suggest that a higher number of birds in India will be exposed to habitat loss related to climate change within the coming 50 years^[22,23]. Climate change will modify the range of many birds found in India, altering habitat range, elevations, and distances away from the equator. Approximately 68% of the habitat area of long-distance migratory birds faces an elevated risk from climate change, as these birds are connected and influenced by climate change during migration^[24,25]. This study delves into how climate variables such as variability of temperature, patterns of precipitation, and habitat fragmentation are affecting bird migration routes, timing, and destinations. The study intends to investigate these changes in order to better understand the complex nature of climate change and its ramifications on bird behaviors. The study seeks to provide important knowledge regarding the complex interactions of climate change and bird migration dynamics to support evidence-based conservation and policy decisions. The main objective of this study is to explore the impact of

unusual changes in temperature and rainfall on migratory bird behavior in Bharatpur, a prominent wetland ecosystem in India.

2. Phenology

Climate variability is already known to affect the phenology of bird species, that is, the timing of key life cycle events such as migration and reproduction^[26]. Since many birds rely on temperature cues to initiate these seasonal behaviors, fluctuations in temperature can disrupt the usual timing of these activities^[27]. As previously stated, birds demonstrate migratory behavior at extraordinarily high levels, resulting in countless remarkable examples of migratory behavior. Each year, billions of individual birds undertake routine cyclical migrations, and shorebirds and seabirds regularly circumnavigate the globe^[28]. A well-documented example of climate's influence on bird behavior comes from a long-term study of great tits in Europe. These birds time their breeding to align with the period when food for their chicks primarily caterpillars is most abundant. Nestlings that are raised during this peak food availability tend to be heavier and have a higher chance of survival^[29]. The caterpillars feed on oak leaves and emerge during the bud burst in early spring, completing their development and pupating in the soil shortly after. This creates a very narrow window in which birds must synchronize reproduction to ensure sufficient food for their offspring. To match this timing, great tits rely on temperature cues to begin their breeding cycle^[30].

Rising temperatures have caused many bird species to begin breeding earlier in the spring. However, the rate of seasonal warming has also accelerated, leading to earlier development of their primary prey, such as caterpillars. As a result, many birds end up laying their eggs too late to fully benefit from the peak in food availability. Essentially, the environmental cues that once synchronized reproduction with prey abundance are no longer reliable. This mismatch can reduce breeding success and, over time, may pose a serious threat to population stability^[31].

These challenges are even more severe for migratory species. Pied flycatchers, for example, have been studied alongside great tits in the same European habitats. Unlike great tits, pied flycatchers spend their winters in tropical Africa and migrate to Europe each spring to breed^[32]. The

change in day length, as opposed to temperature cues, causes their migration at wintering grounds. However, since prey availability in their breeding areas such as caterpillars is driven by temperature, warmer conditions have caused food to emerge earlier in the season. As a result, these birds are now arriving too late to take full advantage of peak food resources^[33]. This mismatch in environmental signals means that migratory timing does not adjust in response to temperature changes, putting the birds at a disadvantage. Consequently, reproductive success has declined, with population reductions of over 90% observed in some regions. The most dramatic declines have occurred in areas where food peaks the earliest, highlighting that reduced prey availability is a key factor in the ongoing population loss^[34].

3. Methods

To explore the relationship between climate variability and migratory bird patterns, this study employed both primary and secondary data sources. As part of the primary research, a survey was conducted among local residents to gather their insights and observations regarding climate change and recent trends in bird migration. Community members, being closely connected to their environment, are often the first to notice shifts in natural patterns. Their familiarity with both historical and current migration behaviors provides valuable context and forms a crucial foundation for the analysis.

Along with primary data, a variety of secondary sources supported the analysis. These included official handbooks from the Bharatpur Bird Sanctuary, global literature on avian behavior, and various reports concerning bird species and their migratory trends. To examine climate-related influences, data on temperature, precipitation, and other relevant indicators were obtained from the Indian Meteorological Department (IMD), as well as from regional climate centers and government publications.

Bird migration can be studied through multiple lenses, including behavioral, ecological, demographic, and geographical perspectives. In this study, the focus is on understanding the relationship between climate variability and the movement patterns of bird communities in the Bharatpur region. To address the research objectives, a combination of quantitative and qualitative methods was employed. A range

of techniques was used to analyze both environmental data and bird migration trends. The key steps undertaken during the course of the study are outlined in the following sections (Table 1).

Table 1. Methodology employed and the key steps undertaken during the course of the study.

Objective	Data have been Collected	Methodology	Techniques
Linkage Between Migration of Birds and Climatic variability	Comparative analysis of the current trends of birds at different geographical locations like water body, wetlands etc.	Various primary and secondary data have been used to create a linkage between Climate variability and migration.	Secondary Data Collection Data collection through Field visits
	Look into the probable impact of different geographical factors like Topography Weather or Climate or Vegetation covers change on birds.	An opinion poll of the locals about both the changing climatic trends and migration of birds.	Opinion and the data can be mapped using GIS techniques by giving different weight age to different indicators.
		Interview Schedule with the sanctuary authorities.	
		Group Discussion with Village Elderly as they have seen decadal changes in the climatic pattern.	

4. Results

The graph illustrates an inverse relationship between winter average temperature anomalies and bird migration. In 1996, a notable drop in the winter temperature anomaly corresponded with a significant increase in bird arrivals. Conversely, in 2010, a rise in the temperature anomaly was associated with a sharp decline in bird migration, reaching nearly zero. This trend suggests that higher winter temperatures negatively impact the influx of migratory birds. There is no proportionate relationship between the average winter temperature anomalies and bird migration (Figure 1).

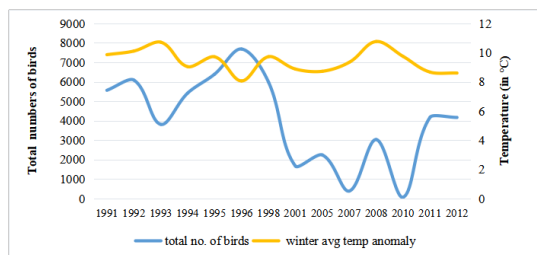


Figure 1. Comparison between Temperature Anomaly and Bird Migration.

Source: Prepared by Author based on IMD data, 2016.

This graph shows the comparison of temperature anomalies with bird migration, excluding the Siberian Crane and Indian Sarus. The pattern observed remains consistent with earlier findings that included these two species. This consistency indicates that the inclusion or exclusion of the Siberian Crane and Indian Sarus does not significantly alter the overall relationship between temperature anomalies and

bird migration. Thus, the broader trend of declining bird migration with increasing temperature anomalies holds true across species groups (Figure 2).

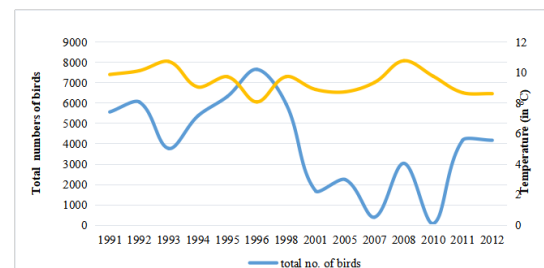


Figure 2. Comparison between Temperature Anomaly and Bird Migration (Excluding Siberian Crane and Indian Sarus).

Source: Prepared by Author based on IMD data, 2016.

This graph shows that as winter average rainfall anomaly increases bird migration decreases with the increases in winter average rainfall anomaly in 1992, 1996, 2008, and 2011, bird migration also decreases but not in any exact proportion. Bird migration was lowest in 2010 and highest in 1996, 1997 (Figure 3).

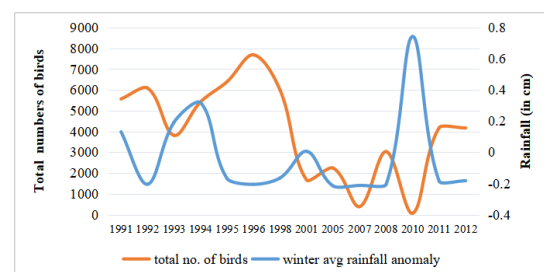


Figure 3. Comparison between Rainfall Anomaly and Bird Migration.

Source: Prepared by Author based on IMD data, 2016.

This graph represents the Comparison between Rainfall Anomaly and Bird migration (Excluding Siberian Crane and Indian Sarus).

An increase in winter average rainfall anomalies is associated with a decline in bird migration. This trend remains consistent even when the endangered yet prominent species of the Bharatpur Bird Sanctuary the Siberian Crane and Indian Sarus are excluded from the analysis. A comparison of bird migration data, both with and without these two species, reveals no significant difference in the overall pattern. This suggests that their exclusion does not substantially affect the observed relationship between winter rainfall anomalies and migratory bird arrivals (**Figure 4**).

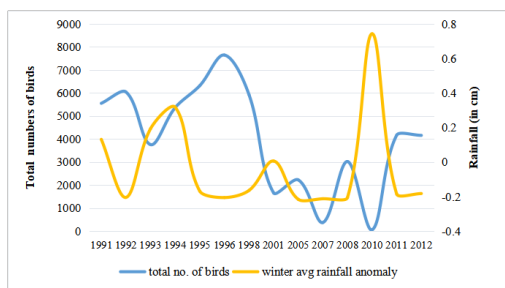


Figure 4. Comparison between Rainfall Anomaly and Bird Migration (Excluding Siberian Crane and Indian Sarus).

Source: Prepared by Author based on IMD data, 2016.

Range and Distribution

As discussed earlier, global warming is altering natural habitats, which can lead to a reduction in the geographic

range of many species. However, in some cases, birds living in tropical and temperate regions may shift their range to higher elevations or latitudes in response to rising temperatures. The effects of climate variability on bird distribution are not uniform worldwide; they vary by region and depend largely on each species' ecological needs. In the study area positioned between the tropical and temperate zones noticeable changes have been observed in bird populations over time. Local species, in particular, have shown significant responses to global warming and rising temperatures, indicating the region's sensitivity to ongoing climate shifts.

The analysis reveals a positive correlation between summer temperatures and the presence of Sarus Cranes, other crane species, and waterfowl. Among all crane groups, the relationship is particularly strong for the Sarus Crane. The data indicate that as summer temperatures rise, the population density of these birds also increases. The overall correlation is statistically significant at the 0.05 level, with coefficients of 0.313 for total crane populations, 0.423 for Sarus Cranes, and 0.311 for waterfowl. Notably, the strongest association is observed between summer temperature and Sarus Crane abundance (0.423), suggesting that this species may respond more sensitively to temperature changes during the summer months (**Table 2**). Also, when the data for the temporal migration of Saras cranes was plotted on a graph, it shows a similar trend as the cranes, with number drastically reduced over the years.

Table 2. Relationship between summer concentration of temperature and all cranes.

Correlations		Total	Sarus	Species	Waterfowl
SCTE	Pearson Correlation	0.313	0.423*	0.276	0.311
	Sig. (2-tailed)	0.086	0.018	0.301	0.325
	N	31	31	16	12

Note: * Correlation is significant at the 0.05 level (2-tailed).

Source: Prepared by Author based on IMD data, 2016.

The population has declined sharply from approximately 250 individuals in 1983 to just around 25 by 2015 representing a reduction of nearly 80–90% over three decades. This dramatic decrease coincides with the period during which global warming has intensified and the effects of climate variability have become increasingly apparent. The trend points to a strong influence of climate variability on the decline in temporal migration patterns. Such disruptions can interfere with the natural life cycle of migratory birds,

affecting their breeding grounds and timing. Over time, these changes may place some species at risk of extinction. Additionally, the relationship between winter temperature patterns and crane populations is reflected in the data presented in **Table 2**.

The analysis indicates a negative correlation between winter temperatures and the populations of all crane groups, including Sarus Cranes, other species, and waterfowl. This relationship is statistically significant across all categories.

The findings suggest that as winter temperatures rise, the number of cranes present tends to decline. The correlation is significant at the 0.05 level, with coefficients of -0.312 for total cranes, -0.425 for Sarus Cranes, and -0.647 for waterfowl. Among these, waterfowl show the strongest negative

correlation with winter temperature, suggesting they are particularly sensitive to warmer winter conditions. Overall, the data confirm that higher winter temperatures are associated with reduced concentrations of crane species (**Table 3**).

Table 3. Relationship between winter concentration of temperature and all cranes.

Correlations		Total	Sarus	Species	Waterfowl
WCTE	Pearson Correlation	-0.312	-0.435^*	-0.318	-0.647^*
	Sig. (2-tailed)	-0.087	0.015	0.230	0.023
	N	31	31	16	12

* Correlation is significant at the 0.05 level (2-tailed).

Source: Prepared by Author based on IMD data, 2016.

The data reveal a negative correlation between moisture levels and the population of Sarus Cranes, other crane species, and waterfowl. However, the level of statistical significance is relatively low across all groups. The results suggest that an increase in moisture corresponds with a decrease in crane populations. While the overall correlation is statistically significant at the 0.01 level, the correlation coefficients vary: -0.85 for total cranes, -0.195 for Sarus Cranes, and -0.215 for waterfowl. Among these, waterfowl show the weakest association with moisture levels (-0.215), as shown in **Table 4**. These findings indicate that higher precipitation levels

are generally associated with lower concentrations of crane species. Additionally, the declining presence of Siberian Cranes over the years, as clearly illustrated in the figure below further reflects the impact of climate variability. Their numbers have steadily declined since 1988, with no recorded sightings by 1994, highlighting a dramatic shift likely linked to changing climatic conditions. In 1996, a marginal increase in the arrival of these cranes was observed. Overall, their numbers have reduced from 40 in 1984 to about 5 in 2012, which also represents a dip of approximately 80%–90 %, similar to the decline observed in Indian Sarus.

Table 4. Association relationship between the moisture and all cranes.

Correlations		Total	Sarus	Species	Waterfowl
Moisture	Pearson Correlation	-0.085	-0.195	0.014	-0.215
	Sig. (2-tailed)	0.649	0.292	0.959	0.501
	N	31	31	16	12

Source: Prepared by Author based on IMD data, 2016.

The analysis shows a strong positive correlation between monsoon rainfall and the population of Sarus Cranes, other crane species, and waterfowl. As rainfall during the monsoon season increases, the concentration of these bird groups also rises. The correlation is statistically significant at the 0.01 level (two-tailed test), indicating a meaningful relationship across all groups. Specifically, the correlation

coefficients are 0.81 for Sarus Cranes, 0.279 for other species, and 0.468 for waterfowl. Among these, Sarus Cranes exhibit the strongest positive association with monsoon rainfall, followed closely by waterfowl. These results suggest that higher rainfall during the monsoon season supports greater abundance of crane populations, likely due to improved habitat and food availability (**Table 5**).

Table 5. Relationship between the concentration of monsoon rainfall and all cranes.

Correlations		Total	Sarus	Species	Waterfowl
MCR	Pearson Correlation	-0.099	0.081	0.279	0.468^*
	Sig. (2-tailed)	0.596	0.666	0.295	0.125
	N	31	31	16	

* Correlation is significant at the 0.05 level (2-tailed).

Source: Prepared by Author based on IMD data, 2016.

Also, apart from the impact of changing monsoon patterns, there is a marked change in the winter rainfall pattern,

which is leading to a different relationship in the region (Table 6).

Table 6. Relationship between winter rainfall concentration and all cranes.

Correlations		Total	Sarus	Species	Waterfowl
WCR	Pearson Correlation	−0.097	−0.149	−0.209	−0.305*
	Sig. (2-tailed)	0.603	0.424	0.438	0.336
	N	31	31	16	12

* Correlation is significant at the 0.05 level (2-tailed).

Source: Prepared by Author based on IMD data, 2016.

The study reveals a negative correlation between winter rainfall and the presence of Sarus Cranes, other crane species, and waterfowl. As rainfall during the winter season increases, the overall concentration of these bird groups tends to decline. Although the correlations are statistically significant at the 0.01 level (two-tailed test), the strength of association is relatively low across all groups. The correlation coefficients are −0.149 for Sarus Cranes, −0.209 for other species, and −0.305 for waterfowl. Among these, waterfowl show the strongest negative association with winter rainfall. These findings suggest that heavier rainfall during the winter months may adversely affect crane populations, with waterfowl appearing particularly sensitive to such climatic conditions (Table 6).

The analysis indicates a weak negative correlation between total annual rainfall and the populations of both Sarus and Siberian Cranes. However, when examining winter rainfall specifically, the Siberian Crane shows a moderate negative correlation, suggesting greater sensitivity to seasonal changes. Similarly, the relationship between total temperature and Sarus Cranes reveals a moderate negative correlation, while for Siberian Cranes, the correlation is weaker. During the winter season, both Sarus and Siberian Cranes exhibit a moderate negative correlation with temperature, highlighting their vulnerability to climatic fluctuations during this critical period (Table 7).

This pie chart illustrates the distribution of local perceptions regarding the impact of climate variability on bird migration, based on data collected from the primary survey. A majority of the respondents stated that they did not know if climate change had an effect on migratory bird movements. Only 13% of the participants acknowledged a connection between climate variability and bird migration. In contrast, 17% disagreed, while another 17 percent remained unde-

cided, highlighting a general lack of awareness or clear opinion among the local population (Figure 5).

Table 7. Correlation between Temperature, Rainfall, Indian Sarus and Siberian crane.

	Sarus	Siberian Crane
Total Rainfall	−0.17	−0.24
Summer Rainfall	−0.2	−0.26
Winter Rainfall	−0.29	−0.35
	Sarus	Siberian Crane
Total Temp	−0.32	−0.29
Summer temp	−0.27	−0.16
Winter temp	−0.39	−0.37

Source: Prepared by Author based on IMD data, 2016.

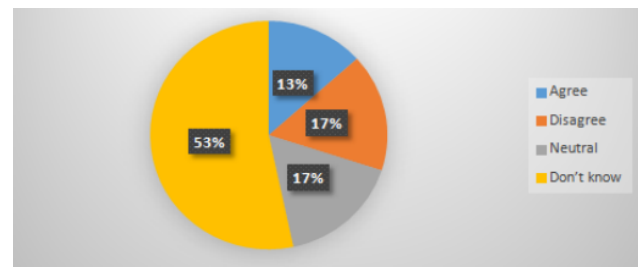


Figure 5. Native input on bird migration and climate.

Source: Prepared by Author based on IMD data, 2016.

5. Discussion

While numerous studies worldwide have explored the effects of climate variability on bird species, the long-term implications remain only partially understood. Although it is widely predicted that many species may face extinction, attributing this solely to climate change is complex, given that species extinction has occurred throughout Earth's history^[7]. What makes the current situation more critical is the interplay between climate variability and human-induced pressures. For example, the cerulean warbler, which winters in the Andes and migrates to the Appalachian Mountains for

breeding, is already facing habitat loss due to coffee plantation expansion in its wintering grounds and coal mining in its breeding areas. These existing threats make the species even more vulnerable to the additional stress of climate change, potentially pushing it closer to extinction over time^[22].

Similarly, birds inhabiting tropical rainforests often avoid crossing open spaces such as roads, as they rely heavily on continuous canopy cover for protection. This fragmentation of habitats due to road construction can significantly limit their ability to shift to new areas in response to changing environmental conditions^[11]. Furthermore, as bird species expand their ranges, they may encounter and compete with native species, creating additional ecological pressures. This can lead to increased competition for food resources, potentially favoring invasive species and disrupting existing ecological balances. In some cases, overexploitation of prey can trigger trophic cascades, affecting multiple levels of the ecosystem. For example, ospreys have been observed preying on other birds, which could become more common if fish populations decline. As birds adjust their ranges due to climate variability, these shifts are likely to result in complex, system-wide ecological interactions^[24].

The disappearance of bird species would lead to the loss of valuable ecosystem services many of which are becoming increasingly vital as the planet continues to warm. For instance, salt marshes act as natural barriers against storm surges, helping to prevent coastal erosion. Birds that inhabit these ecosystems play a crucial role in maintaining marsh health through processes such as nutrient cycling. Without their presence, the integrity of these wetlands would decline, reducing their ability to protect coastal areas from frequent and intense storms^[35]. Similarly, the loss of waterfowl from the wetlands of the Great Plains would not only impact local biodiversity but also diminish recreational opportunities for hunters, along with the revenue generated from hunting permits that support conservation programs. Beyond ecological and economic consequences, bird losses would also carry significant cultural weight. The bald eagle, the national bird of the USA, and considered sacred by many indigenous peoples of the Americas, is projected to lose 75% of its habitat range by 2080. While cultural losses may not be easily measured, their emotional and symbolic significance would be deeply felt and mourned by many depriving future generations of the opportunity to experience these iconic birds firsthand^[36].

The government should enhance its funding for biodiversity protection. In preparing for the future of bird displacement, the species protection in Bharatpur needs to be more effective. Therefore, there should be secure funding for species conservation purposes so it has been shown that more funding leads to scientific effective processes to help conserve at-risk fauna and flora with the right infrastructure and manpower. The government must also establish efficient legal regulations that will define the role, benefit, and responsibility of multiple stakeholders. Nature reserves are created by a variety of departments for a wide range of purposes^[37,38]. The difference between protecting entire bird populations and individual birds should be clarified. With the knowledge gained in this study, it is expected that climate change will increase its effects, which will alter species distributions in the near future. The distribution and abundance of many species of migratory birds will decline based on the climate characteristics of the scenarios. A number of the species may be at risk of extinction^[35,36]. Relevant policies must be made to mitigate climate change. Climate change drastically impacts the distribution of birds, so it is important to stabilize the climate through effective policies^[39]. Temperature is the limiting factor for birds across all of India. Because carbon emissions increase temperature and drastically impact the distribution of birds, we must reduce carbon emissions.

6. Conclusions

In terms of land use and land cover (LULC) changes, the wetland area has shown a steady increase between 2000 and 2017, while other LULC categories have declined slightly. This expansion of wetlands is largely attributed to increased annual rainfall, which has also contributed to the growth of grassland areas. However, the reduction in forest cover poses a significant threat to migratory birds, as it leads to the loss of essential terrestrial habitats. While the increase in wetland areas benefits aquatic bird species, ongoing fluctuations in both summer and winter rainfall and temperature continue to disrupt established migratory patterns. Of particular concern is the rising trend in mean maximum and minimum temperatures, with an observed increase of 0.08 °C in the mean minimum temperature. This warming trend is likely to further influence migratory behavior. One striking example is the dramatic reduction in Siberian

Crane migration since 2002–2003, with arrivals becoming nearly nonexistent. One of the key findings of this study is the evident relationship between temperature, rainfall, and bird migration especially during the winter months. While Siberian Crane migration appears closely linked to winter rainfall, Sarus Cranes are more affected by rising winter temperatures. The study reveals important implications for bird migration and the potential impacts of climate change. By demonstrating the ways in which changing ecological conditions affect bird populations, this study contributes to our understanding of the complex relationships between climate change and biodiversity. These results also illustrate an urgent need for conservation action to protect migratory avian species and habitats in a world marked by unrelenting change.

Author Contributions

Conceptualization, V.C.L., U.R., C.M.M., R.S., M.G.B.; methodology, V.C.L., A.P.M., M.G.B., A.K.; research, V.C.L., A.P.M., C.M.M., R.S., M.G.B., A.K., T.R.N.; writing—original draft preparation, V.C.L., C.M.M., R.S., M.G.B.; writing—review and editing, V.C.L., U.R., C.M.M., R.S., M.G.B., A.K., T.R.N.; supervision, A.P.M., M.G.B., C.M.M.; project administration, V.C.L., A.P.M., M.G.B.; manuscript submission, A.P.M., M.G.B. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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