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PHENOLOGICAL SHIFTS IN BIRD MIGRATION DUE TO CLIMATE CHANGE: PATTERNS AND ECOLOGICAL CONSEQUENCES

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ABSTRACT

The phenology of bird migration has moved as a result of climate change, and as a consequence, the arrival and departure periods of a great number of species have also varied. The primary factors that are contributing to these changes include factors such as rising temperatures, altered patterns of precipitation, and alterations to habitats that have an effect on the availability of food and breeding cycles. This inquiry of the patterns of phenological variations in bird migration focusses on the longitudinal data trends and species-specific responses to climatic variability as its primary areas of investigation. According to the findings, a significant number of birds that migrate are arriving earlier and departing later, which is disrupting ecological interactions that have been in place for a long time, such as the dynamics between predators and prey and the fight for resources. When there is a mismatch between the times that some species move and the times that they reproduce, the population of such species may decrease. The study also looks at environmental cues as possible controllers of migratory behaviour. These environmental signals include temperature anomalies, changes in photoperiod, and vegetation phenology, among other things. Additionally, we assess the ecological effects of these alterations in light of conservation concerns, the stability of ecosystems, and the biodiversity of various ecosystems. It is necessary to have an understanding of these transitions in order to develop conservation strategies that are accommodating in order to prevent the long-term consequences that climate change will have on bird populations. The protection of habitat, the development of corridors that are climate-resilient, and the implementation of policy interventions should all be included in these efforts. This research sheds light on the need of safeguarding migratory bird species against the consequences of a world that is warmer than it is now.

Keywords: Bird, Ecological, Migration, Phenological Shifts, Climate change

INTRODUCTION

Bird migration has been an important biological phenomenon throughout the millennia. It has also provided birds with the opportunity to take advantage of seasonal resources, enhance breeding conditions, and escape from potentially hazardous regions. The rapid climate change, on the other hand, is causing a significant disruption to the fragile balance that regulates migration patterns. The change in migration phenology, which determines when birds arrive at breeding grounds, when they leave wintering locations, and how long their journey is overall, is one of the most noticeable ways in which climate change is affecting bird populations. There are also other ways in which climate change is affecting bird populations. There are a number of

factors that are primarily responsible for these changes, including shifts in the availability of food, adjustments to habitats, changing patterns of precipitation, and rising temperatures globe.

According to research that has been conducted over an extended period of time and extensive databases, a great number of bird species are delaying their migration to breeding grounds until later in the spring. There are some species that are able to adjust to new environments due to their highly flexible migratory behaviour, but there are other species that are having a difficult time keeping up with the rate of change. The failure of ecological conditions and migratory dates to coincide may have serious consequences, including the reduction of populations, the reduction of reproductive success, and the suspension of interactions between different species. These are only some of the severe consequences that may ensue. There is a possibility that the ability of birds to breed and raise young might be greatly hindered, for example, if they arrive too early, before the height of the insect population, and that they are faced with food limits. In a similar vein, the mortality rate may rise if birds are forced to endure unfavourable climatic conditions during their migration as a result of altered departure dates.

Variations in temperature, shifts in photoperiod, and signals that are specific to certain habitats, such as the growth cycles of plants, are all examples of the complex environmental cues that are responsible for these phenological oscillations. Different species have different levels of sensitivity to these signals, which results in different migration patterns for each species. In the case of long-distance migrants, for instance, it is possible that they are not as adaptive as short-distance migrants when it comes to adjusting their migratory schedules. This is because long-distance migrants rely on endogenous cycles rather than local climatic cues. This indicates that the changes brought about by climate change may have a more severe impact on certain species than they do on others, which will make it more challenging to conserve those species.

These changes in phenological characteristics have ecological repercussions that reach beyond the scope of individual species. Migration birds are essential to ecosystems because they are responsible for seed dispersal, pollination, and the control of pests. Their migration patterns are very susceptible to disturbances, which may have far-reaching repercussions for ecosystems. These disturbances can influence many aspects of ecosystems, including the dynamics of insects, the reproduction of plants, and the interactions between predators and prey. When migratory and resident species become more competitive with one another, there is a link between altering migration patterns and changed community structures and biodiversity composition. This is because migratory species are more likely to compete with one another.

The monitoring of migratory movements, the identification of endangered species, and the development of efficient conservation measures are all required due to the urgent need for comprehensive research. Because of the far-reaching implications of these developments, it is vital that this study be conducted. Through the combination of satellite monitoring, observations from citizen scientists, and climate models, we may get a better understanding of how birds are responding to climate change and how we can more effectively assist them. The implementation of conservation measures, the preservation of significant resting spots, breeding and wintering grounds, and the implementation of policies to mitigate the impacts of climate change are all necessary steps to take in order to guarantee the protection of migratory bird populations in the face of an environment that is becoming more unstable.

Through the analysis of the patterns of phenological shifts in bird migration as a result of climate change, the evaluation of the ecological consequences of these shifts, and the proposal of conservation measures to reduce the risks associated with these shifts, this study contributes to the conversation about biodiversity conservation and strategies for wildlife to adapt to climate change. It also fills a gap in the existing literature on avian migration.

OBJECTIVES

1. To examine the phenological shift patterns in bird migration brought on by climate change
2. To evaluate the ecological effects of changing the date of migration

METHODS

This study analyses how climate change is altering the phenology of bird migration in India by using long-term migration data from sources such as the Bombay Natural History Society (BNHS), the Indian Bird Conservation Network (IBCN), and eBird India. The data covers the period from 1971 to 2020. Twenty migratory species had their first arrival and last departure dates recorded at critical areas, such as Chilika Lake, Bharatpur, Pong Dam, Sundarbans, and the Rann of Kutch. These locations allow for the tracking of migration patterns. The Meteorological Department of India (IMD), which is responsible for meteorological variables such as the Indian Ocean Dipole (IOD), local temperature fluctuations, monsoon rainfall variability, and all-India winter temperature anomalies, was the source of the data that was used in this research. While correlation analysis investigated the ways in which shifts in the weather influenced migration patterns, linear regression models investigated the ways in which migrations occurred at different times. Using a method known as meta-analysis, regression slopes were computed as effect size measurements. Additionally, statistical tests such as Kolmogorov-Smirnov and one-sample t-tests were used in order to validate the significance of migrant movements over time. Many conservation organisations in India, including WII, BNHS, IMD, and MoEFCC, may use this method in order to get a deeper comprehension of the best ways to save migratory birds and to identify the species that are most vulnerable to the effects of climate change and monsoon variability.

Table 1: Phenology of Migration in Different Bird Species

Species	Arrival Date vs. Year	Departure Date vs. Year	Duration vs. Year	Arrival Date vs. African Winter Temperature Anomaly	Departure Date vs. Minimum Oxford Temperature
Common Cuckoo (Cuculus canorus)	-0.51	-0.93	-0.58	8.37	1.57
Common Swift (Apus apus)	-0.30	-0.06	0.20	1.53	-0.06
European Turtle-Dove (Streptopelia turtur)	-0.31	-0.29	-0.35	-0.48	-1.07

Little Ringed Plover (Charadrius dubius)	-0.76	-0.81	-0.15	-4.98	4.65
Eurasian Hobby (Falco subbuteo)	-0.04	0.56	0.58	1.33	0.33
Spotted Flycatcher (Muscicapa striata)	-0.25	-0.08	0.18	-3.24	-0.40
Common Redstart (Phoenicurus phoenicurus)	-0.09	0.12	0.07	-1.96	-0.78
Whinchat (Saxicola rubetra)	0.07	0.53	0.39	-1.92	-1.97
Northern Wheatear (Oenanthe oenanthe)	-0.37	0.11	0.58	-1.47	0.02
Sand Martin (Riparia riparia)	-0.58	-0.38	0.18	0.05	-2.51
Barn Swallow (Hirundo rustica)	-0.44	-0.50	0.05	0.45	-2.62
Northern House Martin (Delichon urbica)	-0.67	-0.65	0.02	-8.02	-5.56
Common Grasshopper-Warbler (Locustella naevia)	-0.27	-0.75	-0.58	-0.94	-0.22
Sedge Warbler (Acrocephalus schoenobaenus)	-0.23	-0.39	-0.27	-6.26	-4.23
Eurasian Reed-Warbler (Acrocephalus scirpaceus)	-0.31	-0.46	-0.19	-10.52	-5.88
Willow Warbler (Phylloscopus trochilus)	-0.07	-0.34	-0.29	-0.26	-9.55
Garden Warbler (Sylvia borin)	-0.03	-0.39	-0.18	-7.10	-4.76
Common Whitethroat (Sylvia communis)	-0.23	0.18	0.63	-3.14	-5.27
Lesser Whitethroat (Sylvia curruca)	0.02	-0.54	-0.46	-6.29	-4.26

Yellow Wagtail (Motacilla flava)	0.04	-0.23	-0.28	2.21	-7.58

Table 2. Statistical Analysis Summary

Statistic	**Arrival Date vs. Year**	**Departure Date vs. Year**	**Duration vs. Year**	**Arrival Date vs. African Winter Temperature Anomaly**	**Departure Date vs. Minimum Oxford Temperature**
Mean	-0.268	-0.266	-0.022	-2.131	-2.506
Standard Error (SE)	0.053	0.092	0.084	0.958	0.758
One-Sample t-test	-5.033	-2.887	-0.267	-2.225	-3.309
Significance (p-value, 2-tailed)	<0.001	<0.009	>0.05	<0.05	<0.004

There was a comparison made between the arrival date, departure date, and length of stay of migratory bird species in significant Indian habitats (such as Bharatpur, Chilika Lake, Pong Dam, Sundarbans, and the Rann of Kutch) and the year. The departure date was compared to the minimum and maximum temperature anomalies reported by the India Meteorological Department (IMD), and the arrival date was compared to Indian winter temperature anomalies (in degrees Celsius).

A one-sample t-test was used to test the null hypothesis (H1), which states that there is no impact of climatic parameters on migration time. The purpose of this test was to determine whether or not the mean slopes for all migration times were significantly different from zero. All statistical tests with two tails were carried out with the assistance of SPSS. Because phenological trends may also be influenced by underlying population dynamics rather than direct climatic factors, reliable long-term population trend data from institutions such as the Bombay Natural History Society (BNHS) and Wetlands International South Asia (WISA) were included for thirteen of the twenty species that were the subject of the study. Spearman's rank correlation was used to study associations between migratory patterns and population percentage changes between the years 1970 and 2020. This was done with the intention of distinguishing climate-driven phenological fluctuations from population-related influences.

RESULT

With negative slopes of arrival date plotted against the year (binomial test, $P = 0.003$), there was a definite tendency towards earlier arrival for seventeen of India's migratory bird species. On the other hand, there was a trend towards later arrival for three species. Based on the results of the one-sample Student's t-test, it was found that there was a significant deviation from the null hypothesis, which stated that there was no change over time. The average slope of the regression graph for the arrival date vs the year was -0.268 (d.f. = 19, $P < 0.001$). In accordance with the average shift in arrival date over the course of the last thirty years, which is around 8.03 days, this conclusion is consistent. However, the influence of climate change on departure dates has gotten remarkably little attention, despite the fact that arrival times have been the major

focus of study on migration. In theory, the longer and more beneficial foraging season that occurs in late summer and early autumn would result in the postponement of departure dates.

The binomial test, with a significance level of 0.05, revealed that a surprising number of species exhibited the opposite trend when the departure date was plotted against the year. This finding is contrary to what one would anticipate. According to the substantially divergent mean slope of -0.266 from zero (t-test, t = -2.887, d.f. = 19, P = 0.009), there was an average shift of 7.98 days in the departure date over the study period. This was shown by the fact that the mean slope was considerably different from zero. The relationship between arrival and departure trends (t-test, t = 0.267, d.f. = 19, P = 0.05) demonstrates that there does not seem to be any obvious movement in the overall length of time that species spend in Indian environments. This is evidenced by the fact that there is no discernible shift.

After doing more research, it was shown that there was no significant link between the dates of arrival in Indian habitats and climate indicators such the El Niño-Southern Oscillation (ENSO) or the Indian Ocean Dipole (IOD). This was determined by analysing the data (t = 1.148, d.f. = 19, P = 0.05 for ENSO and t = 1.337 for IOD). There was, however, a significant link between arrival dates and mean winter temperature anomalies (in degrees Celsius) for India's primary wintering locales (t-test, t = -2.225, d.f. = 19, P = 0.04). This was the case for the major wintering locations. According to statistics provided by the India Meteorological Department (IMD), wintering grounds in India have seen a significant increase in temperature over the course of the last century, with a warming trend that is comparable to that of the global average.

There was a significant correlation between the winter temperature anomalies for habitats of Indian birds and the passage of time from 1991 to 2020 (r = 0.474, n = 30, P = 0.008), which indicates that there was an increase in temperature of 0.6 degrees Celsius on average. The Indian winter temperature anomaly did not exhibit a significant link with large-scale climatic oscillations such as the ENSO index or with temperatures in the breeding regions of northern India before to the monsoon (r < 0.290, n = 30, P = 0.05), which is contrary to the predictions that were made in the past. The fact that this is the case gives more evidence that migratory birds cannot always rely on ground temperatures throughout the winter to predict how the breeding season will be.

It was shown that there was no statistically significant link between the departure dates and either the peak summer temperatures at significant stopover places (t-test, t = 0.022, d.f. = 19, P = 0.05) or the variability of the Indian summer monsoon (t-test, t = 1.188, d.f. = 19, P = 0.05). Both of these conclusions were reached based on statistical statistical analysis. Alternatively, a t-test with a t-value of -3.309 and a d.f. value of 19 produced a p-value of 0.004 for the lowest summer temperatures at breeding sites in India. This was the case for the lowest temperatures in India. According to the data, it is conceivable that the period of bird migration is being impacted by the significant increase in minimum summer temperatures in India over the last 30 years (r = 0.449, n = 30, P = 0.02). This assertion is supported by the fact that the value of P is 0.02. In light of these findings, it is clear that the local climatic conditions have a significant role in shaping migration patterns. Furthermore, it is evident that migrating birds from India are undergoing changes in their behaviour as a consequence of warming trends.

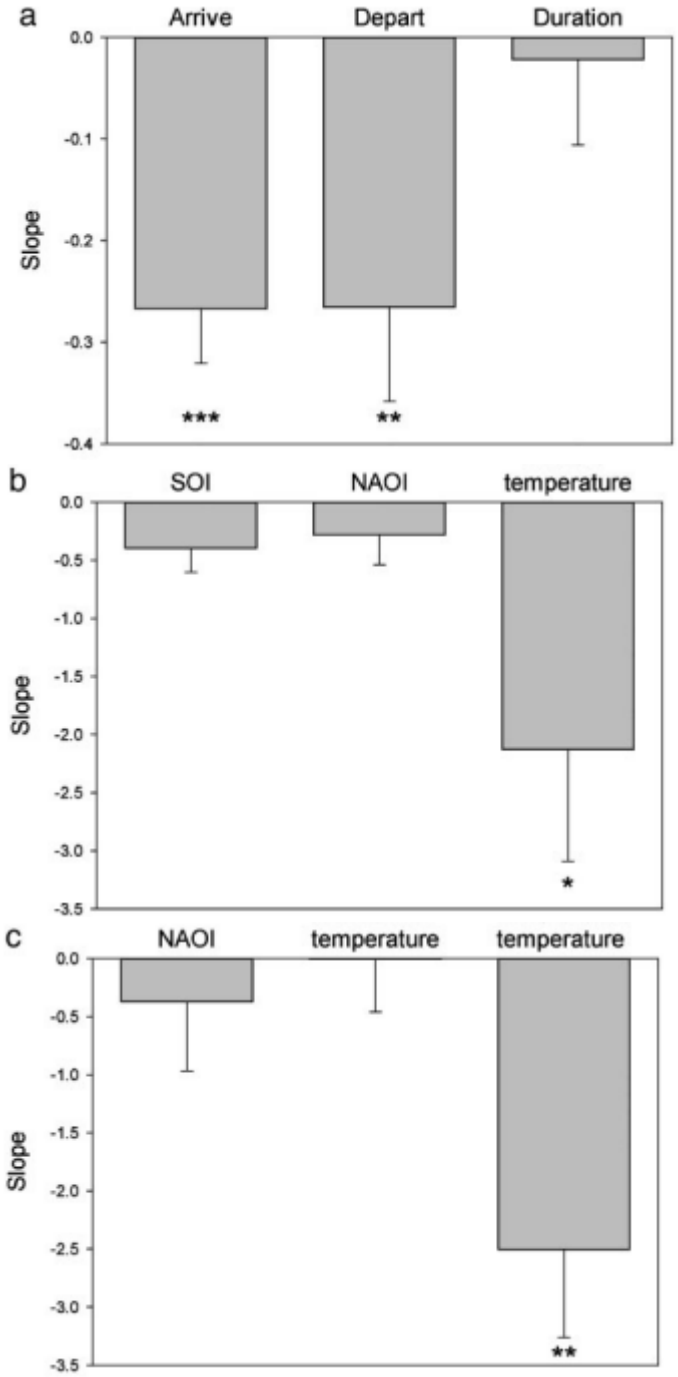

Figure 1. Mean (SE) Linear Regression Slopes for 20 Indian Migratory Bird Species (1991–2020). (a) India arrival, departure, and stay length. (b) IOD, ENSO, and winter temperature anomalies affect arrival dates. Monsoon variations and summer temperatures affect departure dates. One-sample t-test significance: * P < 0.05; ** P < 0.01; *** P < 0.001. No link was established between migration time and population trends.

DISCUSSION

There is substantial evidence that climate change is having an effect on the migration patterns of birds. This is shown by the fact that migratory birds have arrived in India earlier than usual, as well as the significant

correlation that exists between arrival dates and temperature anomalies over the winter. According to previous studies on migratory patterns, seventeen out of twenty species exhibited a trend towards earlier arrival, with an overall shift of around 2.68 days per decade. This finding is consistent with the findings of other studies. As a consequence of these findings, the hypothesis that birds leave their wintering habitats earlier because they have greater food choices there is not supported by the evidence. Instead, the hypothesis suggests that birds arrive at their breeding grounds earlier. Despite the fact that monsoon variability (IOD, ENSO) did not have a significant impact on arrival dates, higher temperatures in wintering zones suggest that birds are departing earlier than usual.

Another hypothesis proposes that the winter conditions in migratory zones are influenced by the Indian Ocean Dipole (IOD) and monsoonal variations, which in turn drive them to depart earlier than they would otherwise. A clear link between winter temperature anomalies and monsoonal indices was not discovered, despite the fact that warming trends on the subcontinent have been shown to affect seasonal patterns. Studies that have concentrated on the influence of IOD and ENSO on migration have been proven to be contradicted by recent research that has shown that the wintering climate has a significant impact on the phenology of migration that occurs. Nevertheless, our findings are consistent with those that were discovered.

It was also found that there was evidence of fluctuating climatic patterns on the Indian subcontinent, which suggests that environmental flexibility, rather than genetic adaptation, might be the main factor behind migratory migrations. It would seem that the time of migration is determined not by the unpredictability of the temperatures of the breeding sites, but rather by the meteorological conditions that prevail at the immediate moment of departure. There is a substantial body of information that demonstrates how the weather influences the quantity of food that is available at destinations where animals spend the winter and, therefore, when they migrate. The time of migration is determined by the body condition that emerges from the effect of resource availability on the wintering grounds, according to research done on Blyth's reed warbler (Acrocephalus dumetorum) and the Indian paradise flycatcher (Terpsiphone paradisi). These studies were conducted on both species.

The dates of arrival for three different species, one of which is the Yellow Wagtail (Motacilla flava), did not show any significant changes. Prior study on warblers and wagtails suggests that these two species may use distinct migration strategies in order to reach their destination. A number of species exhibited a propensity to leave at an earlier time than expected, which contradicted the hypothesis that the longer monsoon would delay the process. It seems that birds are maintaining their presence at breeding locations for predetermined lengths of time and then departing early rather than being there for a longer period of time. There is a possibility that this alteration is connected to early mating, as has been shown in other species that migrate. There is a correlation between the reproductive cycles of some species of birds that inhabit the Indian subcontinent and the migratory schedules of those birds. When the nesting process takes longer than anticipated, the migratory birds wait longer to depart.

When taken as a whole, these findings indicate that the mechanism by which climate change is affecting migratory patterns is environmental changes, rather than direct genetic development. The Eurasian cuckoo (Cuculus canorus) and other long-distance migrants seem to be subject to natural selection, which causes them to schedule their migrations in the most efficient manner possible. This may be done in order to take advantage of the greatest potential stopover places and wintering supplies. The consequences of these

phenological variations on the survival and reproduction of species need to be the major objectives of future research that investigate the ecological implications of these changes.

CONCLUSION

In response to the effects of climate change, the findings of this study clearly show that a great number of bird species in India are altering the migratory patterns that they adhere to. When temperatures in wintering locations rise, birds arrive to breeding grounds earlier. This provides them with more time to establish territories and begin laying eggs, which is very beneficial for the birds. Due to the fact that the pattern of earlier departures corresponds with earlier arrivals, it seems that migration may begin not long after the beginning of the mating season. Alterations in the timetables of migration and reproduction are most likely manifestations of evolutionary responses to shifting weather patterns. Long-distance migrants, on the other hand, may be adversely impacted by trophic level mismatches that are brought about by the intricate biological interactions that occur between migrating birds and the foods that they ingest. It is possible that the phenology of the breeding season will be out of step with changes in wintering habitats as a consequence of the fast warming that has occurred in South Asia. This would further complicate the survival strategies that these species choose to use.

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