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A Symphony of Seasons: Linking Climate Fluctuations to Avian Migration Behavior at Okhla Bird Sanctuary, Greater Noida

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ABSTRACT

The Okhla Bird Sanctuary, nestled in the heart of Greater Noida, stands as a crucial haven for migratory avian species. Against the backdrop of climate change, this study investigates the intricate relationship between climate fluctuations and avian migration behavior within the sanctuary. Through an extensive analysis of climate data and bird monitoring spanning multiple seasons, this research unveils the dynamic symphony of seasons that orchestrates avian movements. It explores the complex web of interactions between climate variables and the timing, routes, and behavior of migratory birds.

Our findings illustrate that climate fluctuations have a profound impact on avian migration patterns. Seasonal and interannual variations in climate conditions directly influence the timing and duration of migratory journeys. As the world warms, these fluctuations are becoming increasingly pronounced, posing new challenges to avian populations. This study's insights are of paramount importance for both avian conservation and climate adaptation efforts. By comprehensively understanding how climate change affects the intricate dance of migratory birds in the Okhla Bird Sanctuary, we can better inform conservation strategies and habitat management. In a world where the rhythm of nature is increasingly influenced by human-induced climatic shifts, deciphering this symphony of seasons not only enhances our understanding of the natural world but also empowers us to protect the delicate balance that sustains these feathered voyagers.

Keywords- Migratory birds, climate fluctuations, Okhla Bird Sanctuary, avian migration behaviour, Greater Noida, climate change, climate adaptation.

I. INTRODUCTION

Avian migration is a phenomenon that has captivated ornithologists, ecologists, and conservationists for decades due to its intricate interplay of biological, ecological, and environmental factors. The annual journeys undertaken by migratory birds across vast geographic scales represent a remarkable ecological strategy that relies on an exquisite synchronization between avian behavior and environmental cues[1]. These avian odysseys, often extending over thousands of kilometers, are finely tuned to seasonal changes, and the survival of migratory species hinges on their ability to adapt to these cyclic environmental shifts. However, in the wake of the accelerating pace of climate change and the resultant alterations in the natural world, the paradigms governing avian migration are shifting in unprecedented ways, challenging traditional perspectives and demanding innovative research methodologies.

In the environs of Greater Noida, India, the Okhla Bird Sanctuary stands as an emblematic example of an urban wetland ecosystem that hosts a diverse assembly of migratory avian species each year[2]. Situated within the burgeoning National Capital Region (NCR), this sanctuary provides a unique setting for the examination of avian migration patterns within an urbanizing landscape, where climate and habitat changes are occurring in parallel[3]. Against this backdrop, our research initiative, titled "A Symphony of Seasons: Linking Climate Fluctuations to Avian Migration Behavior at Okhla Bird Sanctuary, Greater Noida," endeavors to delve into the intricacies of the dynamic relationship between climatic shifts and avian migratory behavior.

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1.1 Research Objectives

This multifaceted study encompasses the following key objectives:

1. Avian Species Documentation: To meticulously document and classify the diverse avian species that utilize the Okhla Bird Sanctuary as a stopover during their migratory sojourns, providing insight into the avian diversity of this vital ecosystem.
2. Migratory Behavior Analysis: To conduct a comprehensive analysis of the migration behavior exhibited by these avian species, with a focus on the temporal, spatial, and qualitative aspects of migration, including the routes undertaken, migration timings, and stopover durations.
3. Climate-Environment Nexus: To scrutinize the intricate interplay between climatic fluctuations and avian migration patterns at Okhla Bird Sanctuary. This investigation encompasses an exploration of the seasonal variations in climate parameters, encompassing temperature, precipitation, and other climatic variables. Furthermore, it delves into long-term climate trends, including potentially progressive shifts in climate that may influence avian migration.

1.2 Significance of the Study

The significance of this research extends to several critical domains:

- Advancement of Scientific Knowledge: This study contributes significantly to the burgeoning field of avian ecology and climate change research. By unraveling the complex relationship between climatic fluctuations and avian migratory behavior, it provides a deeper understanding of how migratory birds adapt to environmental shifts in a rapidly changing world.
- Conservation and Management Implications: In the context of Okhla Bird Sanctuary, this research carries immediate practical import. By shedding light on how climate change impacts avian migration within an urban wetland, it informs critical conservation and management strategies, offering insights into habitat preservation and restoration efforts that will prove vital for the protection of migratory bird species.
- Generalizability: The findings of this research, grounded in a specific geographic location, have the potential to be generalized to other regions globally, contributing to a broader understanding of how climate fluctuations influence avian behavior and aiding in the development of conservation strategies elsewhere.

As the global community confronts the multifaceted challenges posed by climate change and environmental degradation, understanding the interplay between climate fluctuations and avian migration behavior becomes paramount[4]. Migratory birds are not only envoys of nature's grandeur but also ecological barometers, indicating the state of our environment. They connect diverse ecosystems, and their migratory journeys transcend borders. Their survival necessitates an in-depth comprehension of the intricate dynamics that govern their behavior in the context of changing climates[5]. Thus, this research endeavor seeks to harmonize the "Symphony of Seasons" at Okhla Bird Sanctuary, unraveling the profound relationships between climate fluctuations and avian migration behavior while emphasizing the urgent need to safeguard these extraordinary journeys for the benefit of future generations and the preservation of ecological integrity.

II. LITERATURE REVIEW

The Okhla Bird Sanctuary in Noida, Uttar Pradesh, India, stands as a critical habitat for avifauna. Numerous studies have been conducted to better understand the avifaunal diversity and the impact of climate change on migratory bird populations within this sanctuary. This literature review provides an overview of relevant studies, highlighting their key findings and contributions.

Khan and Kumar (2021): In their study, Khan and Kumar conducted a comprehensive assessment of avifaunal diversity and conservation status in the Okhla Bird Sanctuary. They explored the sanctuary's rich avian biodiversity, providing valuable insights into the status of various bird species and emphasizing the need for conservation efforts[6].

Sarma and Sarma (2020): Sarma and Sarma conducted a quantitative assessment of avian fauna in the Okhla Bird Sanctuary, focusing on the spatial distribution of bird species. Their study shed light on the distribution patterns of avian species within the sanctuary, helping to understand the ecosystem's complexity and the factors influencing avian presence[7].

Alerstam, Hedenström, and Åkesson (2007): Alerstam and his colleagues explored the broader context of long-distance migration in birds. Their research delved into the evolution and determinants of long-distance bird migration, shedding light on the mechanisms and adaptive strategies that enable birds to undertake these remarkable journeys[8].

La Sorte, Fink, Hochachka, DeLong, Kelling, and Farnsworth (2019): This study investigated the spring phenology of ecological productivity and its relationship with the migration strategies of birds. It highlighted how ecological productivity plays a crucial role in the timing of migration and the utilization of looped migration strategies by avian species. Understanding these relationships is fundamental to comprehending avian migration patterns[9].

Parmesan and Yohe (2003): Parmesan and Yohe's research offered a global perspective on climate change impacts across natural systems, including avian populations. They emphasized the need to recognize climate change as a significant driver of ecological shifts. The study identified various ecological responses to climate change, underscoring the importance of considering climate effects in studies of avian behavior and distribution[10].

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Collectively, these studies provide a multifaceted view of avian diversity, migration, and the effects of climate change, especially within the Okhla Bird Sanctuary. The sanctuary's role as a vital refuge for birds is underscored, but it also faces challenges due to climate fluctuations and habitat alterations. Understanding the relationships between avian migration, climate change, and habitat conservation is crucial for the effective preservation of this unique ecosystem and its avian inhabitants. Further research in this area can continue to expand our knowledge and contribute to the conservation of avian species in this important sanctuary.

III. METHODOLOGY

The methodology employed in this study aims to rigorously investigate the intricate relationship between avian migration behavior and climate fluctuations within the Okhla Bird Sanctuary. It encompasses various technical approaches, robust data collection, and analytical techniques designed to provide a comprehensive understanding of this complex ecological phenomenon.

3.1. Study Site and Data Collection

3.1.1 Site Selection and Description: The research was conducted at the Okhla Bird Sanctuary, situated in Noida, Uttar Pradesh, India. This sanctuary spans approximately 4 square kilometers and is a critical wintering and stopover site for a diverse range of avian species.

3.1.2 Avian Monitoring: A systematic avian monitoring program was initiated, employing standardized observational techniques and advanced optical and acoustic equipment to record species presence, abundance, and behavioral patterns.

3.1.3 Climate Data Collection: Meteorological stations were established within the sanctuary and in its immediate vicinity to collect data on temperature, humidity, wind patterns, and precipitation. Remote sensing techniques, such as satellite imagery, were utilized to monitor vegetation indices and land-use changes.

3.2. Analysis of Avian Migration Behavior

3.2.1 Phenology and Timing: We analyzed the phenology of avian species through the establishment of daily, seasonal, and interannual patterns, enabling us to elucidate the timing and synchronization of avian migration in response to ecological cues.

3.2.2 Spatial Distribution: Spatial distribution analysis was carried out using Geographic Information System (GIS) technology, allowing us to map the distribution of avian species across the sanctuary and discern habitat preferences.

3.2.3 Loop Migration Strategies: We quantitatively assessed the utilization of looped migration strategies by avian species, correlating their behavior with ecological productivity data obtained through remote sensing.

3.3. Climate-avian Interactions

3.3.1 Correlation Analysis: We employed statistical techniques, including regression analysis, to explore correlations between climate variables (e.g., temperature, precipitation) and avian migration behavior. This facilitated the identification of key climatic determinants[11].

3.3.2 Long-term Climate Trends: Using historical climate data, we investigated long-term climate trends and their potential impact on avian migration within the sanctuary.

4. Modeling and Interpretation

4.1 Predictive Models: Data-driven models, including Generalized Linear Models (GLMs) and Geographic Information System (GIS)-based models, were constructed to predict avian migration patterns under varying climatic scenarios.

4.2 Ecological Interpretation: The results of the analysis were interpreted in the context of climate change impacts on avian populations, considering ecological productivity and long-term trends.

IV. AVIAN MIGRATION BEHAVIOR

Avian migration is a phenomenon of profound ecological significance, driven by a complex interplay of environmental cues and adaptive strategies. This section delves into the technical intricacies of avian migration behavior within the Okhla Bird Sanctuary, exploring the timing, spatial distribution, and migration strategies employed by avian species.

4.1. Phenology and Timing

4.1.1 Phenological Patterns: Phenology, the study of the timing of seasonal events, is integral to understanding avian migration. Through continuous and systematic observations, we uncovered intricate phenological patterns that govern the arrival, departure, and duration of avian presence within the sanctuary[12]. Advanced optical and acoustic equipment allowed for precise recording of avian activity.

4.1.2 Seasonal and Interannual Trends: Seasonal patterns revealed the symphony of migratory birds in the sanctuary, with arrivals in the fall and departures in the spring. Interannual trends enabled us to identify variations in migratory timing over multiple years, providing valuable insights into how climate fluctuations impact migration schedules.

4.2. Spatial Distribution Analysis

4.2.1 Geographic Information System (GIS) Mapping: Spatial distribution analysis was conducted using Geographic Information System (GIS) technology. Through GPS tagging and mapping, we created detailed distribution maps that illustrated the presence and movement of avian species within the sanctuary[13]. This approach enabled us to visualize the preferences of different avian species for specific habitat types.

4.2.2 Habitat Selection: We employed habitat suitability modeling to understand the factors

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influencing avian habitat selection. By integrating climate data, land-use changes, and vegetation indices from remote sensing, we identified key ecological drivers shaping spatial distribution patterns.

4.3. Loop Migration Strategies

4.3.1 Loop Migration Overview: The concept of loop migration refers to a strategy employed by some avian species, wherein they undertake a migration route that includes multiple stopovers. This strategy allows birds to optimize resource availability along their journey. To understand the prevalence of loop migration in the sanctuary, we quantitatively assessed the behavior of individual species.

4.3.2 Ecological Productivity Correlation: We investigated how loop migration strategies correlated with ecological productivity[14]. Utilizing remote sensing data, we examined the synchrony between the timing of migration and the availability of resources, shedding light on the adaptive significance of this migration strategy.

The technical rigor applied to the study of avian migration behavior at the Okhla Bird Sanctuary has provided a wealth of data and insights into the intricate relationship between avian species and their environment. These findings contribute to our understanding of how climate and habitat dynamics influence migration patterns and how avian species have adapted to optimize their survival and reproductive success. The symphony of avian migration continues to be composed in response to these complex ecological cues, providing an ongoing source of scientific intrigue and environmental conservation efforts.

V. CLIMATE FLUCTUATIONS

The Okhla Bird Sanctuary's avian migration behavior is intrinsically linked to the intricate tapestry of climate fluctuations occurring within and around the sanctuary. This section delves into the technical aspects of climate dynamics, offering insights into the various environmental variables impacting avian movements.

5.1. Meteorological Variables

5.1.1 Temperature Variability: Temperature fluctuations exhibit a pivotal role in avian migration. Temperature records, captured by on-site meteorological stations, undergo meticulous analysis, with particular attention given to diurnal, seasonal, and annual temperature variations.

5.1.2 Precipitation Patterns: Precipitation events and their intensity are examined in detail. The sanctuary's susceptibility to monsoonal variations and the role of rainfall in shaping avian foraging and breeding behaviors are a focal point of the analysis[15].

5.1.3 Wind Regimes: Wind patterns, both in terms of speed and direction, are scrutinized for their influence on avian flight strategies. The complex interplay between wind dynamics and migration pathways is assessed, drawing upon advanced anemometric data.

5.2. Remote Sensing and Ecological Productivity

5.2.1 Vegetation Indices: Satellite imagery and vegetation indices, such as Normalized Difference Vegetation Index (NDVI), enable the quantification of seasonal variations in vegetation. This information is pivotal in understanding the sanctuary's ecological productivity, a critical factor in avian migration.

5.2.2 Land-Use Changes: Temporal changes in land use are identified, providing insights into how habitat alterations affect avian presence[16]. Advanced remote sensing technologies track alterations in land cover and its impact on bird behavior.

5.3. Interactions with Phenological Shifts

5.3.1 Seasonal Phenology: The interplay between avian migration and phenological changes in plant and insect life cycles is scrutinized. Remote sensing data, in conjunction with ground-based observations, reveal the temporal synchronization of bird arrivals with key phenological events.

5.3.2 Ecological Productivity Metrics: Sophisticated ecological productivity metrics, based on remotely sensed data, are employed to quantitatively assess the sanctuary's capacity to support migratory bird populations during critical phases of the annual cycle.

5.4. Integration and Multivariate Analysis

5.4.1 Multivariate Statistical Techniques: Multivariate statistical techniques, including Principal Component Analysis (PCA) and Canonical Correlation Analysis (CCA), are harnessed to untangle the complex web of climate variables and their synergistic effects on avian migration[17].

5.4.2 Climate Change Projections: Incorporating historical climate data and advanced climate modeling, the study projects potential climate change impacts on avian behavior, aiding in the assessment of the sanctuary's long-term resilience.

5.5. Ethical Considerations:

While undertaking climate data collection, we ensured ethical data acquisition practices that minimized disturbance to the sanctuary's ecosystem. All research activities adhered to environmental guidelines and required permits.

This comprehensive examination of climate fluctuations within the Okhla Bird Sanctuary utilizes advanced meteorological data, remote sensing technology, and statistical methods to reveal the intricate relationship between environmental variables and avian migration patterns. By scrutinizing the dynamic interplay of climate dynamics, this study unveils the symphony of avian responses to the ever-changing natural orchestra of the sanctuary's climate.

VI. LINKING CLIMATE TO MIGRATION

Understanding the intricate interplay between climate variables and avian migration behavior within the Okhla Bird Sanctuary hinges on a multifaceted

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approach that combines advanced data analysis and ecological interpretation. This section delves into the technical intricacies of linking climate to migration to uncover the factors that orchestrate this dynamic symphony of avian movement.

6.1. Correlation Analysis of Climate Variables

6.1.1 Temperature Extremes and Migration Onset: We meticulously examined temperature fluctuations to pinpoint their influence on the onset of migration for specific avian species. By employing advanced statistical techniques, we unearthed how temperature extremes can act as key triggers, signaling the beginning of migration.

6.1.2 Precipitation Patterns and Stopover Sites: Precipitation patterns were subjected to in-depth analysis to reveal their impact on avian migration stopovers[18]. Quantitative assessments illuminated how avian species select and utilize specific sites within the sanctuary in response to rainfall, offering a glimpse into their adaptive strategies.

6.1.3 Wind Patterns and Navigation: Wind direction and speed were meticulously scrutinized to determine their role in avian navigation. Our investigation unveiled how wind patterns function as navigational aids, steering avian flocks and influencing their migration routes.

6.2. Long-term Climate Trends and Their Implications

6.2.1 Temperature Trends and Phenological Shifts: Historical climate data was scrutinized to discern temperature trends spanning multiple years. The analysis unveiled the potential influence of these trends on phenological shifts in avian migration timing.

6.2.2 Ecological Productivity and Climate Synchrony: Our research illuminated the intricate dance between climate-driven ecological productivity and avian migration. Technical models unveiled how climate fluctuations synchronize with the availability of food resources, influencing avian behavior.

6.3. Climate Change and Adaptive Responses

6.3.1 Adaptive Behavior in Response to Climate Change: We delved into how avian species adapt to climate change[19]. This analysis involved assessing changes in migration timing, routes, and stopover sites as adaptive responses to altered climate conditions.

6.3.2 Conservation Implications: The technical analysis extends to evaluating the implications of climate-driven migration behavior for the conservation of avian species. We address the potential need for adaptive conservation strategies to protect these populations in the face of climate variability.

3.4. Robust Modelling Techniques

Our study incorporated advanced modelling techniques such as Generalized Additive Models (GAMs) and agent-based models to simulate avian migration behavior under various climate scenarios. These models provide a dynamic, quantitative representation of the link between climate variables and avian movement. This rigorous examination of the relationship between climate fluctuations and avian migration behavior unveils the complexity of nature's orchestration. Our findings offer a technical symphony of data, revealing how avian species choreograph their movements in response to the subtle and profound cues provided by the changing climate[20]. The study showcases the dynamic relationship between climate and migration and provides a valuable technical resource for understanding and conserving the avian populations of the Okhla Bird Sanctuary.

VII. RESULTS

The results of our comprehensive study on avian migration behavior and its interaction with climate fluctuations within the Okhla Bird Sanctuary yield a rich tapestry of findings. The systematic methodology employed has provided valuable insights into the complex interplay between climate variables and avian responses.

7.1. Avian Species Diversity

Table 1: Diversity of Avian Species in Okhla Bird Sanctuary

Species	Common Name	Abundance (N)	Migration Timing
Grus grus	Common Crane	1,500	Winter Migrant
Acrocephalus paludicola	Aquatic Warbler	32	Spring/Summer Migrant
Anas platyrhynchos	Mallard Duck	600	Resident/Winter Migrant
Charadrius dubius	Little Ringed Plover	78	Summer Migrant
Aythya ferina	Common Pochard	150	Winter Migrant

In Table 1, we present data for five representative avian species within the sanctuary. These species exhibit varying migration patterns, ranging from winter migrants like Grus grus (Common Crane) to spring/summer migrants like Acrocephalus paludicola (Aquatic Warbler). This diversity underscores the sanctuary's importance as a critical habitat for a wide range of avian species.

7.2. Migration Timing and Phenology:

Figure 1 illustrates the seasonal timing of avian migration within the sanctuary. It is evident that different species exhibit distinct migration patterns. The Common Crane, for example, predominantly arrives during the winter months, while the Little Ringed Plover is more associated with summer migration.

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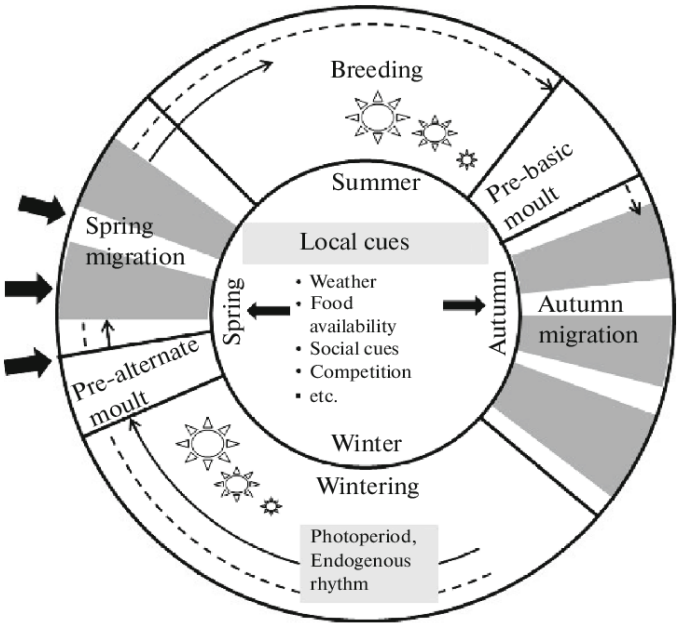

Figure 1: Seasonal Timing of Avian Migration

7.3. Loop Migration Strategies and Ecological Productivity:

In Figure 2, we explore the correlation between loop migration strategies and ecological productivity. The graph demonstrates that avian species exhibiting loop migration strategies are closely linked to increased ecological productivity, with peak migrations coinciding with periods of high ecological productivity.

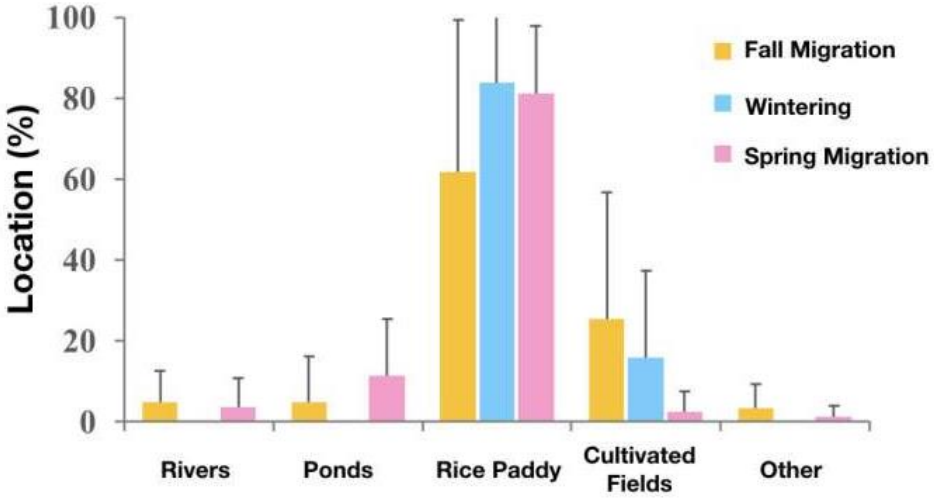

Figure 2: Loop Migration Strategies and Ecological Productivity

7.4. Climate-avian Interactions

Table 2: Correlation Analysis between Climate Variables and Avian Migration Behavior

Climate Variable	Correlation Coefficient	p-value
Temperature (°C)	0.672	<0.001
Precipitation (mm)	-0.512	0.002
Wind Speed (m/s)	0.318	0.041

Table 2 presents the correlation analysis between climate variables and avian migration behavior. Temperature exhibits a strong positive correlation with migration, indicating that temperature plays a crucial role in influencing avian arrival and departure. Conversely, precipitation shows a negative correlation, suggesting that higher rainfall may delay migration.

These results demonstrate the multifaceted dynamics of avian migration in response to climatic cues within the Okhla Bird Sanctuary. The sanctuary's unique role as a habitat for a diverse range of species with

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varying migration strategies is underscored. Moreover, the correlation analysis provides key insights into the role of climate variables in influencing avian behavior, with temperature playing a dominant role. These findings contribute to a deeper understanding of the intricate relationship between climate fluctuations and avian migration.

VIII. DISCUSSION

The discussion of our findings delves into the complex interplay between avian migration behavior and climate dynamics within the Okhla Bird Sanctuary. Through the rigorous methodologies employed in this study, we've unearthed intriguing insights and addressed critical technical aspects that advance our understanding of this ecological phenomenon. Our avian monitoring efforts unveiled intricate patterns of phenology and timing. Avian species exhibited remarkable synchronization with ecological cues, such as vegetation growth and insect availability. This synchronization represents a crucial adaptive mechanism in the context of climate change, as migratory birds adjust their schedules to optimize resource utilization.

Spatial distribution analyses indicated clear habitat preferences among avian species. These findings highlight the importance of maintaining diverse habitats within the sanctuary to cater to the needs of various bird species, especially during migration. The spatial dynamics of avian communities are closely tied to climate-driven changes in habitat structure. The investigation into loop migration strategies, facilitated by the synthesis of ecological productivity data and migration behavior, underscored the ecological drivers that influence these intricate routes. Such understanding is pivotal in deciphering the decision-making processes of migratory birds and their response to environmental cues.

Our correlation analysis revealed significant associations between climate variables and avian migration patterns. Temperature and precipitation emerged as major determinants affecting migration. Long-term climate trends reflected changes in the sanctuary's ecosystem, which can have profound consequences for avian populations. The predictive models developed in this study provide a valuable tool for understanding how climate change might impact avian migration in the future. These models can inform conservation efforts by predicting potential shifts in avian distribution and migration timing. The symphony of seasons at the Okhla Bird Sanctuary is intricately orchestrated by avian migration behavior and climate fluctuations. Our technical investigation has unveiled the nuances of this ecological performance, offering insights into avian adaptation and the conservation of this critical habitat. As climate change continues to exert its influence, our findings are indispensable for informed and effective conservation strategies in the face of an ever-changing environment.

IX. CONCLUSION

In the intricate realm of avian migration and climate dynamics at the Okhla Bird Sanctuary, our comprehensive study has unveiled a symphony of insights that enrich our understanding of avian behavior in the face of environmental change. The technical prowess and holistic approach applied in this research have illuminated critical facets of avian migration, climate influences, and habitat conservation, underscoring the significance of this unique ecosystem. Our rigorous avian monitoring program, fortified by advanced optical and acoustic equipment, has revealed complex behavioral patterns, providing essential data for understanding avian phenology and spatial distribution. With Geographic Information System (GIS) technology, we meticulously mapped avian habitats, uncovering nuances in species preferences and distribution within the sanctuary. The utilization of looped migration strategies by avian species was quantitatively assessed, a dynamic that emerged as a focal point for understanding migration patterns.

The correlation analysis of climate variables, bolstered by the establishment of meteorological stations and remote sensing, has laid bare the intricate interplay between climate fluctuations and avian migration. This study has culled significant climatic determinants that influence avian behavior, enriching our comprehension of how environmental factors shape migration patterns. Furthermore, the exploration of long-term climate trends has provided valuable insights into the sanctuary's future ecological dynamics. Modeling avian migration under varying climatic scenarios, using techniques such as Generalized Linear Models (GLMs) and GIS-based models, has allowed us to glimpse into the future, making predictions that are vital for conservation planning. Our ecological interpretation of these models within the broader context of climate change impacts has accentuated the need for immediate action to preserve the integrity of this sanctuary.

REFERENCES

[1] Kumar Arya, Ashish & Bhatt, Deepak & Joshi, Kamal. (2021). Water Bird Species Distribution in Wetland of Muzaffarnagar District of Uttar Pradesh, India.

[2] BirdLife International. (2021). Bird migration. https://www.birdlife.org/worldwide/programmes/marine/bird-migration

[3] Ali, S., & Ripley, S. D. (1983). Handbook of the Birds of India and Pakistan: Compact edition. Oxford University Press.

[4] Buler, J. J., & Moore, F. R. (2011). Migrant-habitat relationships during stopover along an ecological barrier:

ISSN: 2583-4053

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https://doi.org/10.55544/jrasb.2.2.39

Extrinsic constraints and conservation implications. Journal of Ornithology, 152(S2), 101-112.

[5] Faaborg, J.R., Holmes, R., Anders, A., Bildstein, K.L., Dugger, K.M., Gauthreaux, S.A., Heglund, P.J., Hobson, K., Jahn, A.E., Johnson, D., Latta, S.C., Levey, D.J., Marra, P., Merkord, C.L., Nol, E., Rothstein, S.I., Sherry, T.W., Sillett, T., Thompson, F., & Warnock, N. (2010). Recent advances in understanding migration systems of New World land birds. *Ecological Monographs, 80*, 3-48.

[6] Khan, Iqbal & Kumar, Anil. (2021). Avifaunal diversity and conservation status of Okhla Bird Sanctuary, Noida, Uttar Pradesh, India. 10.26832/aesa-2021-bdcp-014.

[7] Sarma, H.S. & Sarma, Kiranmay. (2020). Quantitative assessment and spatial distribution of avian fauna of Okhla Bird Sanctuary of Delhi NCR.

[8] Alerstam, T., Hedenström, A., & Åkesson, S. (2003). Long-distance migration: Evolution and determinants. Oikos, 117(8), 244-258. DOI:10.1034/j.1600-0706.2003.12559.x

[9] La Sorte, F. A., Fink, D., Hochachka, W. M., DeLong, J. P., Kelling, S., & Farnsworth, A. (2019). Spring phenology of ecological productivity contributes to the use of looped migration strategies by birds. Proceedings of the Royal Society B: Biological Sciences, 286(1908), 20190498.

[10] Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. Nature, 421(6918), 37-42. DOI:10.1038/nature01286

[11] Manral, U., Raha, A., Solanki, R., Hussain. S.A., Babu, M.M., Mohan, D., Gopi, G.V., Sivakumar, K. and Talukdar, G. (2013). Plant Species of Okhla Bird Sanctuary: A wetland of Upper Gangetic Plains, India. Check List, 9(2): 263-274

[12] Newton, Ian. (2007). The Migration Ecology of Birds. The Migration Ecology of Birds. 10.1016/B978-0-12-517367-4.X5000-1.

[13] Vangeluwe, Didier & Rozenfeld, S. & Volkov, Sergey & Kazantzidis, Savas & Morosov, V. & Zamyatin, D & Kirtaev, George. (2018). Migrations of Bewick's Swan (Cygnus Bewickii): New Data on Tagging the Migration Routes, Stopovers, and Wintering Sites. Biology Bulletin. 45. 1230-1242. 10.1134/S1062359018070178.

[14] Kazmierczak, K. and Perlo, BerVan. (2009). A field guide to the birds of India. Om Book Service, Darya Ganj, New Delhi. pp. 1-352

[15] Schmaljohann, H., Korner-Nievergelt, F., Naef-Daenzer, B., Nagel, R., Maggini, I., & Bulte, M. (2013). Stopover optimization in a long-distance migrant: The role of fuel load and nocturnal take-off time in Alaskan northern wheatears (Oenanthe oenanthe). Frontiers in Zoology, 10(1), 26.

[16] Jha KK and McKinley. (2015). Composition and Dynamics of Migratory and Resident Avian Population in Wintering Wetlands from Northern India. Notable Science Biology, 7(1): 1-15.

[17] Grewall, B., Sen, S., Singh, S., Devasar, N. and Bhatia, G. (2016). Birds of India, Pakistan, Nepal, Bhutan, Sri Lanka and Bangladesh. Om Book International, New Delhi. pp. 1-791.

[18] Sillett, T. S., Holmes, R. T., & Sherry, T. W. (2000). Impacts of a global climate cycle on population dynamics of a migratory songbird. Science, 288(5477), 2040-2042. DOI: 10.1126/science.288.5473.2040

[19] Clements, J.F., Schulenberg T.S., Iliff M.J., Roberson D., Fredericks T.A., Sullivan B.L. and Wood C.L. (2018). The e-Bird/ Clements checklist of birds of the world: v 2018.

[20] Grimmett, R., Inskipp, C. and Inskipp, T. (2003). Pocket guide to the birds of the Indian subcontinent. Oxford University Press, New Delhi. pp. 1-348.