

The Interplay between Bird Migration Behavior and Genetic Diversity

Lin Jing ✉

Biotechnology Research Center, Cuixi Academy of Biotechnology, Zhuji, 311800, China

✉ Corresponding author email: 2644034884@qq.com

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Abstract Avian migration is a significant phenomenon in biodiversity, and genetic diversity during migration is crucial for the adaptability and survival of species. This review begins by introducing the diversity of avian migration behavior and the pivotal role of genetic diversity. It then delves into analyzing the impact of climate change on avian migration, particularly focusing on the influence of rising temperatures on migration patterns and habitats. The review explores the potential effects of these changes on the genetic diversity of birds. It also discusses genetic adaptation and changes, revealing the survival strategies adopted by birds in response to climate change. Furthermore, it examines the response of genetic diversity in avian migration, including its relationship with adaptability, gene flow, migration paths, and genomic stability. These analyses are crucial for better understanding the dynamic changes in genetic diversity during avian migration, leading to the development of more effective conservation policies and ecosystem management. Through in-depth exploration, we can better protect and preserve avian migration, ensuring its continued prosperity in the face of challenges posed by climate change.

Keywords Bird migration; Genetic diversity; Climate change; Adaptability; Ecosystem management

The relationship between bird migration behavior and genetic diversity constitutes a stunning biological landscape, revealing a magical and ancient tradition in nature. The miraculous behavior not only demonstrates the wisdom of bird survival, but also highlights the perfection of the natural ecosystem. However, as global climate change becomes increasingly frequent and significant, bird migration faces unprecedented challenges. In recent decades, temperatures have continued to rise and extreme weather events have occurred frequently, which have had a profound impact on the migration of birds. The rise in temperature not only changes the seasonal climate pattern, but also directly affects the breeding, migration time, location, and route selection of birds. These changes are directly related to the behavioral habits, habitat selection, and resource allocation of birds, affecting the genetic diversity and genetic structure of the entire bird population (Tamarío et al., 2019).

Genetic diversity plays a crucial role in bird migration. It is the foundation for bird populations to adapt to environmental changes and determines their ability to adapt to different environmental pressures (Berthold, 2002). However, climate change may have a negative impact on genetic diversity, making migratory populations more susceptible to genetic bottlenecks and drift, thereby reducing their adaptability and survival ability (Morganti, 2015).

This study aims to comprehensively explore the impact of climate change on genetic diversity in bird migration. By conducting in-depth analysis of the relationship between gene diversity and adaptability, gene flow and migration pathways, as well as genome stability and environmental changes, this study will examine the biological responses of bird populations to high temperature and climate change. Exploring the relationship between bird migration and genetic diversity in depth will also provide a more comprehensive understanding and insight for the protection and sustainable management of global ecosystems. Exploring the impact of climate change on bird migration is an inevitable choice for in-depth thinking and research on this magnificent phenomenon in nature. Only through continuous deepening of understanding can people better protect and maintain this rich and diverse Earth ecosystem.

1 Bird Migration and Genetic Diversity

1.1 Overview of bird migration

The migration of birds is a miracle of life, performing magnificent rhythms in the changing seasons. They cross the sky, from south to north, from east to west, carrying the wonders of the ecosystem on their migration journey. The ancient migration tradition is not only an instinct of birds, but also a key factor in ecological balance. However, as the climate continues to change, this magnificent migration faces many challenges.

Bird migration varies in scale and distance. Some birds only migrate for short distances within relatively localized areas, while others migrate for long distances across thousands of miles, continents, and even ocean currents. These movements are not accidental, they are closely related to seasonal climate change. Environmental factors such as temperature, light, and wind play important roles in bird migration. The changes in these factors will directly affect the feeding locations, breeding areas, and overall migration paths of birds. Migration is not only related to seasonal environmental changes, but also closely related to reproductive cycles, reproductive behavior, and foraging habits. During the migration process, birds require a large amount of energy to support long flights, and many birds need to search for food to maintain their physical strength during the migration. Therefore, the smooth progress of migration is crucial for the survival and reproduction of birds (Morganti, 2015).

The migration of birds covers a wide range of species and regions, and the migration patterns and scales of each bird species vary (Table 1). For example, the Red billed Quelea exhibits billions of swarms on the African savannah, exhibiting astonishing large-scale swarm migration; The Arctic tern, on the other hand, has the longest migration route in the world, spanning tens of thousands of miles within a year, crossing the poles of the entire Earth. These migrations of different scales and distances not only vary in itinerary, but also directly affect the genetic diversity of bird populations.

Table 1 Representative migratory bird information (Xu et al., 2021)

The order, family, and genus of migratory birds	Representative types	Distribution location	Migration distance
Craniformes, crane family, white crane genus	<i>Grus leucogeranus</i>	Distributed mostly in Eurasia and Africa	8 000 kilometers
Chariotiformes, gull family, tern genus	<i>Sterna paradisaea</i>	Distributed near the Arctic	70 00 kilometers
Storyliformes, Egret family, Egret genus	<i>Egretta garzetta</i>	Distributed mostly in Africa, Madagascar, and Eurasia	900 kilometers
Falcons, family Falconidae, genus Falcon	<i>Falco peregrinus</i>	Distributed mostly near the Arctic Circle	6 400 kilometers
Passeriformes, family Orioles, genus Orioles	<i>Phylloscopus trochilus yakutensis</i>	Distributed mostly near Siberia	13 000 kilometers

The different patterns and scales of bird migration have varying degrees of impact on genetic diversity. In small-scale migration, the genetic relationships of the population may be closer, and the flow of genetic information during the migration process is relatively limited. In contrast, birds that migrate over long distances globally may experience more extensive gene flow, and populations from different regions may exchange genetic information more frequently, thereby affecting the genetic diversity and structure of the population. Therefore, understanding and studying the impact of migration of different scales and distances on gene diversity is crucial for comprehensively grasping the genetic characteristics of bird ecosystems.

1.2 The concept of genetic diversity

Genetic diversity refers to the degree of diversity in genotype and gene frequency within a specific species or population. It involves the differences in individual genes within a population, including genotype diversity, changes in gene frequency, and the magnitude of genetic variation. In the context of bird migration, genetic diversity focuses on the differences between individual genes within a population, which directly relates to the adaptability of the population to environmental changes.

Genetic diversity plays a crucial role in bird populations. It is the cornerstone for a group to adapt to environmental changes and cope with stress. Rich genetic diversity means that there is more genotype and genetic information within the population, thereby increasing the likelihood of the population responding to changes in the external environment. This diversity helps to improve the survival ability of populations and reduce the risk of ecosystem and population collapse caused by environmental changes (De Meester et al., 2017).

The genetic diversity of bird migration is not only reflected in the migration behavior itself, but also in the selection of migration paths, adaptability to different habitats, and rapid adaptation to new environments. During migration, genetic diversity of populations may be challenged due to changes in geography and environment. This change may trigger gene flow, variation, and selection, thereby having a profound impact on the adaptability and survival strategies of the population (Lü et al., 2021). Some birds may change their migration paths or residence locations due to climate change to adapt to new environmental conditions. The behavioral change may lead to changes in gene flow and genetic structure within the population, increasing the frequency of different genotypes and thus affecting the survival strategy of the population. The richness of genetic diversity can provide populations with greater genetic adaptability, making them more likely to survive in constantly changing environments.

1.3 The impact of migration types on gene diversity

The migration types of birds have a significant impact on gene diversity. Different types of migration patterns, such as seasonal migration, partial migration, or periodic migration, can have varying impacts on genetic diversity and distribution within a population.

Seasonal migration may trigger broader gene flow, as migratory birds navigate multiple geographic locations during the migration season, leading to gene exchange and mixing. This frequent gene flow may reduce genetic differences between migrating populations, increase gene exchange in the overall population, and thus maintain relatively high gene diversity. In contrast, birds that migrate partially or regularly may exhibit greater genetic differentiation. If some individuals or groups choose to stay in place while others choose to migrate, this may lead to gene segregation and differences. Over the long term, this may result in genetic diversity differences between different subspecies, populations, or individuals.

The type of migration can also have an impact on genetic adaptability and population genetic structure. Migration strategies are related to environmental adaptability, therefore bird populations under different migration patterns may exhibit different adaptive genotypes to different environmental pressures (Hoffmann and Sgrò, 2011). Furthermore, migration strategies may affect the gene frequency and genetic structure within bird populations, resulting in varying degrees of gene differentiation and differences, which may affect the adaptability and survival ability of the population.

2 Genomic Stability and Environmental Changes

2.1 The challenge of environmental changes to genomic stability

Genomic stability plays a crucial role in the relationship between bird migration and environmental changes, and this stability is the cornerstone of species genetic diversity and adaptability. The changes in the environment challenge the stability of the genome, and their impact involves multiple aspects such as genetic variation, genotype frequency changes, and gene flow.

Environmental changes may trigger genetic variations in the genome. Climate anomalies, habitat destruction, or interference from human activities may induce mutations or rearrangements in the genome, which may lead to changes in the genetic structure of species. This variation may sometimes have a positive impact on the adaptability of bird populations, but it may also increase the risk of disease or reduce the adaptability of the population. Environmental stress may also lead to changes in specific genotypes or gene frequencies in the genome. Some specific genotypes may be more adaptable to changing environments, therefore, under environmental pressure, the frequency of these genotypes may increase. However, such changes may lead to a decrease in genetic diversity, increasing the risk of disease or other environmental pressures on the population (Tamarío et al., 2019).

Moreover, environmental changes may also affect gene flow in the genome. Bird migration is often influenced by seasonal and regional environments, but when these environments change, the migration path and location may change. It may lead to a decrease or increase in gene flow between migratory populations, thereby affecting the maintenance and development of gene diversity.

2.2 The relationship between genomic stability and avian adaptability

Genomic stability plays an important role in the adaptability of bird populations. It affects genetic diversity, adaptive evolution, and the health status of populations, thereby affecting the survival and reproductive ability of birds in the face of environmental changes.

Genomic stability affects the genetic diversity of bird populations. A genome stable population often has richer genetic diversity, which enables the population to better adapt to various environmental conditions. However, when genomic stability is affected, it may lead to a decrease in genetic diversity, thereby reducing the population's ability to adapt to environmental changes. Genomic stability is also closely related to the adaptive evolution of birds. When the environment changes, bird populations with stable genomes may be more likely to cope with such changes through natural selection and adaptive evolution. The stability helps to maintain some adaptive genotypes, allowing birds to maintain high adaptability in new environments. In addition, genomic stability is closely related to the population health and survival ability of birds. A population with a stable genome is more likely to avoid the spread of genetic diseases and maintain the health and survival of the population (Pulido and Berthold, 2010).

2.3 The relationship between genetic stability of bird populations and climate change

There is a close relationship between the genetic stability of bird populations and climate change. With global temperature changes and frequent extreme weather events, the genetic stability of bird populations is facing unprecedented challenges. Climate change may limit gene flow, lead to a decrease in gene diversity and an increase in genetic drift, thereby affecting population stability and adaptability.

Climate change may hinder gene flow in bird populations. Migratory birds often choose migration paths and locations based on seasonal and environmental changes to adapt to different seasons and resource changes. However, climate change may alter migration pathways or locations, limiting gene flow between different populations and affecting the genetic stability of some populations (Pauls et al., 2012). Climate change may also lead to a decrease in genetic diversity in bird populations. Changes in ecosystems may affect the habitat and resource allocation of birds, resulting in changes in certain genotypes or gene frequencies. The change may lead to a decrease in genetic diversity, thereby reducing the population's ability to adapt to new environments. In addition, climate change may lead to increased genetic drift in bird populations. When the environment undergoes drastic changes, the population may face adaptive pressure, which may lead to drastic changes in the frequency of certain genotypes in the genome, resulting in genetic drift.

3 Genetic Diversity Response in Bird Migration

3.1 Genetic diversity and adaptability

Genetic diversity provides a genetic basis for bird migration, endowing them with the ability to adapt to different environments and cope with various pressures. This diversity is crucial for the health and reproduction of populations, especially when facing various challenges during migration.

Genetic diversity provides bird populations with stronger adaptability, enabling them to better cope with different environmental pressures. Under different climate and habitat conditions, different genotypes may exhibit higher survival and reproductive abilities. This adaptability enables birds to adapt to new environmental conditions more quickly during migration. Genetic diversity can also improve the survival rate and reproductive success rate of populations. Individuals with more genetic variations are usually more resilient and able to resist environmental changes and disease stress. During migration, this resilience helps bird populations overcome various challenges and maintain their healthy state (Coppack and Both, 2002).

For example, during bird migration, individuals with more genetic variations may be more likely to adapt to different migration paths or new habitats. These mutated genotypes may enable birds to better utilize resources in different geographical environments, thereby improving their chances of survival and reproduction. In addition, genetic diversity in combating pathogens or other environmental pressures is also crucial. Birds with more resistance genotypes may be better able to avoid disease transmission or adapt to survival challenges under different environmental conditions during migration.

3.2 Gene flow and migration pathways

The understanding of bird migration pathways and the impact of gene flow on population genetic diversity provide important clues for humans to understand the genetic structure and population dynamics of bird populations. These knowledge not only help explain the genetic changes during migration, but also provide important scientific basis for the protection and management of bird populations.

Gene flow describes the mutual exchange of genotypes between different geographical regions. The migration path of birds typically spans multiple geographical regions, including different environments and habitat conditions. This migration pattern leads to gene exchange between different populations, forming a complex and diverse gene flow network. This flow not only shapes and influences genetic diversity within populations, but also establishes genetic connections between populations on a global scale.

The choice of migration path has an impact on the distribution of different genotypes in the population. Some birds may choose relatively stable migration paths, following similar migration routes and habitats. But other birds may flexibly adjust their migration paths to cope with different environmental conditions and resource changes. This path selection may lead to genotype differences between populations on different paths, forming a genotype composition specific to migration paths (Knudsen, 2011). For example, some migratory bird populations may choose to stop or forage during their migration, and meet or mix with other populations during this period. This mutual communication may lead to mixing between different genotypes and have an impact on the genetic structure and diversity of the population. In addition, in some cases, geographical barriers along migration paths may lead to relative isolation of certain genotypes in specific regions, which may result in populations in these regions having specific genetic characteristics (Charmantier and Gienapp, 2013).

3.3 The relationship between genomic stability and environmental changes

There is a close relationship between genomic stability in bird migration and environmental changes. Genomic stability refers to the degree to which the genome maintains and maintains itself in both time and space, as well as its ability to respond to external environmental pressures.

During migration, bird populations may be influenced by various environmental factors, such as temperature, climate change, availability of food resources, and changes in habitat conditions. The changes in these environmental factors may have an impact on genome stability, thereby affecting the adaptability and survival ability of bird populations. The maintenance of genomic stability is crucial for the adaptability and survival of birds during migration (Dawson et al., 2011). Some genotypes may be more adaptable, able to better adapt to environmental changes and maintain their stability. This genomic stability may affect the adaptability and survival rate of bird populations, and is crucial for ecosystem function and ecological balance during migration (Berthold, 2002).

4 Prospect

The relationship between bird migration and genetic diversity is a fascinating and challenging field. In this field, it can be seen how bird populations rely on their genetic diversity to adapt to constantly changing environments. Migration is a crucial part of bird life cycle, involving complex processes from seasonal climate change to adaptation to different habitats. The migration path selection and gene flow of birds play an important role in shaping the genetic structure and diversity of populations. In this field, future research will aim to gain a deeper understanding of the impact of different migration patterns on genotype distribution, as well as the role of genomic stability in environmental changes.

Genetic diversity has been proven to be crucial for the adaptability of bird populations. Individuals with more genetic variations are often better able to adapt to different environmental pressures during migration. This diversity provides key mechanisms for resisting diseases and adapting to new environments, increasing opportunities for the survival and reproduction of bird populations. Future research will delve deeper into how these genotypes affect the selection of migration pathways and their resource utilization capabilities in different geographical environments. On the other hand, environmental changes pose a challenge to genome stability, which is crucial for the survival ability of bird populations. With global climate change, birds may face changes in their migration paths, which may limit gene flow and affect the maintenance of gene diversity. Therefore, an understanding of genomic stability under environmental changes will provide us with more information about the survival ability and adaptability of populations.

Technological innovation will be an important driving force for future bird conservation. The development of genomics and remote sensing technology will provide humans with more refined genetic information and habitat monitoring data, which will provide more support for the study of bird migration and genetic diversity. Interdisciplinary cooperation will also be the key to future research, integrating knowledge from ecology, genetics, and environmental science can provide humans with a more comprehensive understanding, assist in bird conservation, and promote sustainable development of ecosystems.

Overall, the interaction between bird migration and genetic diversity will continue to lead the forefront of research in biology and environmental science. Future research will delve deeper into these relationships, providing richer and more comprehensive insights into bird conservation, ecosystem robustness, and human sustainable use of the environment. The continuous exploration in this field is expected to provide more solutions for humans, thereby better understanding how bird migration shapes the genetic structure of populations, and how genetic diversity affects the survival and reproductive ability of birds under different environmental conditions. These research findings will have important inspiration and guidance for the maintenance of biodiversity, ecosystem balance, and sustainable environmental management.

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