



The Impacts Of Climate Change On The Life Style Of Birds

Dr.U. Srineetha

Assistant professor in zoology, Govt. College for Women, Pulivendla

Abstract

Climate change stands as one of the most pressing environmental issues of the 21st century, exerting profound and wide-ranging effects on ecosystems and biodiversity. Today's organisms have evolved from ancestors that endured significant climatic fluctuations in the past; however, they now face a host of new, human-induced challenges, including the unprecedented pace of current climate change. Birds, in particular, serve as highly sensitive indicators of these shifts, with their migration patterns, breeding schedules, feeding habits, and habitat preferences increasingly disrupted by altered climate conditions. Since birds rely heavily on stable environmental cues for their survival, even minor changes in temperature, rainfall, or seasonal timing can trigger substantial ecological imbalances. Migration and reproduction in many avian species are governed by internal biological mechanisms shaped by long-term natural selection, ensuring that arrival at and departure from breeding grounds align with moderate weather, peak food resources, and adequate nesting sites. Egg-laying timing typically depends on both internal clocks and local environmental conditions to maximize food availability for raising offspring. Climate change is disrupting this balance, causing mismatches in food supply, snow cover, and other critical factors, which could jeopardize successful migration and reproduction unless species adapt to new conditions. Non-migratory (resident) birds are also vulnerable if changes in temperature or precipitation lead to seasonal mismatches in breeding and food availability. Projections that many current climate types will vanish while novel climates emerge indicate that avian communities may be reshaped dramatically through extinctions and range shifts. This study seeks to investigate the complex effects of climate change on bird life, using case studies, field observations, and ecological modeling. A clearer understanding of how birds respond to environmental pressures will help identify the intrinsic and extrinsic factors that could hinder their ability to adapt—an urgent priority for future research.

Keywords: bird, climate change, bird migration, avian reproduction penology, egg lying

Introduction

Significant alterations in the Earth's climate are already visible, and further changes are anticipated to persist into the next century. Climate change represents a substantial threat to avian populations. As global temperatures increase and weather patterns evolve, bird populations are facing considerable disruptions in their migration paths, breeding schedules, feeding behaviors, and distribution areas. These alterations not only jeopardize the survival of individual species but also have ripple effects on ecological stability and biodiversity. It is essential to comprehend how climate change affects the lifestyles of birds to formulate effective conservation strategies and safeguard the complex web of life that relies on them. Living organisms are faced with numerous anthropogenic challenges, including climate change, habitat degradation, the

introduction of new chemicals and non-native species into ecosystems, the emergence of new pathogens, and the transport of pathogens into regions where they have not previously existed, along with the synergistic impacts of these and other factors.

The number of relatively untouched ecosystems worldwide is rapidly declining. By 2050, it is projected that 15–37% of existing animal and plant species on Earth may face extinction, and by 2100, half of all species on the planet could be at risk of extinction. It is crucial to anticipate how current human-induced challenges will impact key species within ecosystems, so that, if feasible, measures can be implemented to mitigate these threats. This paper will concentrate on the challenges that contemporary changes in global climate present for the annual cycles of birds, particularly focusing on the timing of migration and reproduction, as well as the mismatches between food availability and the energetically demanding phases of this cycle.

2. Estimating the effect of climate change on bird populations methods

Evaluating the effects of climate change on bird populations requires a range of methods and analyses designed to comprehend the intricate connections between climate fluctuations and avian reactions.

2.1. Population monitoring and data collection

Long-term Bird Surveys: Regularly conducting standardized bird surveys over extended periods is essential for monitoring changes and trends in bird populations. A notable example is the Breeding Bird Survey (BBS) in North America, which has supplied long-term data for numerous species. **Point Count Method:** This technique entails documenting birds that are seen and heard at predetermined locations for a specified time frame. It is frequently utilized alongside GIS mapping and environmental data to evaluate species distribution and abundance patterns. **Mist Netting and Banding:** The process of capturing birds with mist nets and affixing unique bands or tags enables researchers to collect comprehensive information regarding age structure, sex ratios, individual health, and to monitor their movements and survival rates. **Acoustic Monitoring:** Automated recording devices placed in diverse habitats capture bird vocalizations, facilitating species identification through sound analysis and the detection of elusive or nocturnal birds [2]. **Citizen Science Initiatives:** Involving the public through platforms such as Bird or the Great Backyard Bird Count promotes extensive data collection on bird diversity and distribution, harnessing the contributions of many observers.

2.2 Analyzing the impact of climate change

Long-term Bird Surveys: Regularly conducting standardized bird surveys over extended periods is essential for monitoring changes and trends in bird populations. Notable examples include the Breeding Bird Survey (BBS) in North America, which has supplied long-term data for numerous species. **Point Count Method:** This technique entails documenting birds that are seen and heard at designated points for a predetermined duration. It is frequently utilized alongside GIS mapping and environmental data to assess species distribution and abundance patterns. **Mist Netting and Banding:** The process of capturing birds with mist nets and affixing unique bands or tags enables researchers to collect comprehensive information regarding age structure, sex ratios, individual health, and to monitor their movements and survival rates. **Acoustic Monitoring:** Automated recording devices placed in various habitats capture bird vocalizations, facilitating species identification through sound analysis and the detection of elusive or nocturnal birds. **Citizen Science Initiatives:** Involving the public through platforms such as Bird or the Great Backyard Bird Count promotes extensive data collection on bird diversity and distribution, harnessing the contributions of many observers.

2.3. Connecting climate to population changes

Long-term Bird Surveys: Regularly conducting standardized bird surveys over extended periods is essential for monitoring changes and trends in bird populations. An example of this is the Breeding Bird Survey (BBS) in North America, which has supplied long-term data for numerous species. **Point Count Method:** This technique entails documenting birds that are seen and heard at designated points for a specific duration. It is

frequently utilized alongside GIS mapping and environmental data to assess species distribution and abundance patterns. **Mist Netting and Banding:** The process of capturing birds with mist nets and affixing unique bands or tags enables researchers to collect comprehensive information regarding age structure, sex ratios, individual health, and to monitor their movements and survival rates. **Acoustic Monitoring:** Automated recording devices placed in various habitats capture bird vocalizations, facilitating species identification through sound analysis and the detection of elusive or nocturnal birds. **Citizen Science Initiatives:** Involving the public through platforms such as Bird or the Great Backyard Bird Count promotes extensive data collection on bird diversity and distribution, harnessing the contributions of many observers.

Addressing challenges and future directions

Multi-species and Cross-regional Studies: Broadening research efforts beyond specific species and geographical areas to evaluate the wider impacts of climate change on avian communities across extensive spatial dimensions. **Integrating Multiple Methods:** Merging conventional and innovative monitoring techniques with advanced analytical methods to enhance the precision and reliability of estimations. **Addressing Data Limitations:** Tackling issues associated with data deficiencies in particular regions (such as the tropics) and constraints in data accuracy or detectability rates for specific species. **Collaboration and Data Sharing:** Encouraging cooperation among researchers and institutions, and fostering data sharing to improve the collective comprehension of climate change effects on birds. By integrating these methodologies and strategies, researchers aim to achieve a more thorough understanding of the intricate and varied impacts of climate change on bird populations, which is crucial for formulating effective conservation and adaptation strategies for a sustainable future.

2. Climate change through geological history

Climate change is not a phenomenon of recent origin; it has been an inherent aspect of Earth's geological history, shaping the evolution and distribution of life for millions of years. From ice ages to prolonged periods of warming, these climatic shifts have had profound impacts on ecosystems—birds included. Fossil evidence reveals that ancient avian species either adapted, migrated, or became extinct in response to past climate fluctuations. Such historical events highlight the susceptibility of bird life to environmental change and offer valuable insights into how present-day species may respond to current and future climatic challenges. Studying the influence of past climate variations on birds allows researchers to better understand the long-term resilience and vulnerability of avian populations in an era of accelerating global warming.

While modern discussions often emphasize the rapid warming and climate shifts observed over the last century, it is essential to recognize that climate change is neither new nor a rare occurrence in Earth's history. Data from both instrumental records and paleoclimatic proxies—such as tree ring growth patterns, stalagmites, ice cores, coral reef formations, and sediment deposits from oceans and lakes—show that climate fluctuations have been the rule rather than the exception throughout the planet's existence. Periods of relative climatic stability have alternated with episodes of dramatic and, at times, abrupt change.

It is estimated that roughly 99% of all species that have ever lived are now extinct. Although extinction has been a constant feature in the evolutionary process, at least five major mass extinction events have been identified in which an unusually high number of taxonomic groups disappeared. Many of these extinctions appear to have coincided with significant climatic transformations. For example, fossil records indicate that numerous tropical molluscan species vanished during the cooling period associated with the onset of northern glaciations in the Pliocene, about three million years ago. Nonetheless, some groups endured even the large-scale losses of plant and animal life during major climatic transitions, such as the Cretaceous–Tertiary boundary approximately 65 million years ago, and these survivors became the ancestors of many species living today.

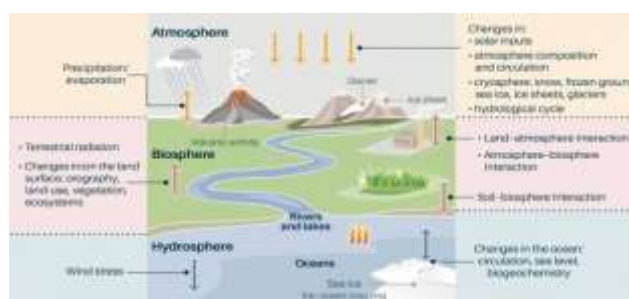


Fig:1 Climate change through geological history

3. Current global climate change

The present age of global climate change—largely fueled by human actions such as the burning of fossil fuels, deforestation, and industrial farming—is leading to swift alterations in environmental conditions worldwide. Birds, which are closely linked to seasonal changes and ecological signals, are among the wildlife groups most visibly impacted. Increasing temperatures, modified precipitation patterns, and a higher occurrence of extreme weather events are disrupting bird migration paths, breeding schedules, food supply, and habitat stability. Numerous species are compelled to migrate toward higher latitudes or altitudes, while others are experiencing population declines or even facing extinction. These transformations not only jeopardize avian diversity but also interfere with the essential ecological functions that birds fulfill, ranging from pollination to pest management. As indicators of ecosystem vitality, the reactions of birds to climate change serve as urgent alerts regarding the condition of our planet—and the necessity for prompt conservation efforts.

4. Biological effects of current global climatic change

The biological impacts of the ongoing global climate change are becoming increasingly apparent in bird populations worldwide. As temperatures rise and weather patterns grow more erratic, birds are undergoing substantial alterations in their physiology, behavior, and life cycles. Key biological processes such as migration, breeding, molting, and feeding are being disrupted by modified seasonal cues and changes in habitat. For instance, numerous species are now migrating earlier in the spring or breeding out of alignment with peak food availability, resulting in diminished reproductive success. In certain areas, birds are experiencing reductions in body size or are shifting their ranges in search of more favorable climates. These biological reactions illustrate the stress that birds endure as they attempt to adapt to swiftly changing environmental conditions. Comprehending these effects is crucial not only for the conservation of bird species but also for monitoring the wider ecological consequences of global climate change. Fig. 2: Temperature Effects on All Birds, Generalist Birds, and Specialist Birds. This figure represents the percentage change in bird biodiversity (both the number of birds and the number of species) due to an unconditional one-standard-deviation increase in high-temperature days (relative to corresponding days between 0 and 15 °C). Generalist and specialist species are classified according to the methodology outlined in the Data section. The dark markers indicate the point estimates, while the whiskers represent the 95 percent confidence intervals. All regressions account for route fixed effects, year-by-month fixed effects, route-level precipitation, and its quadratic term as detailed in the text. Standard errors (in parentheses) are clustered at the route and state-by-year level. Significance levels are indicated as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Numerical results are illustrated in Fig. 2.

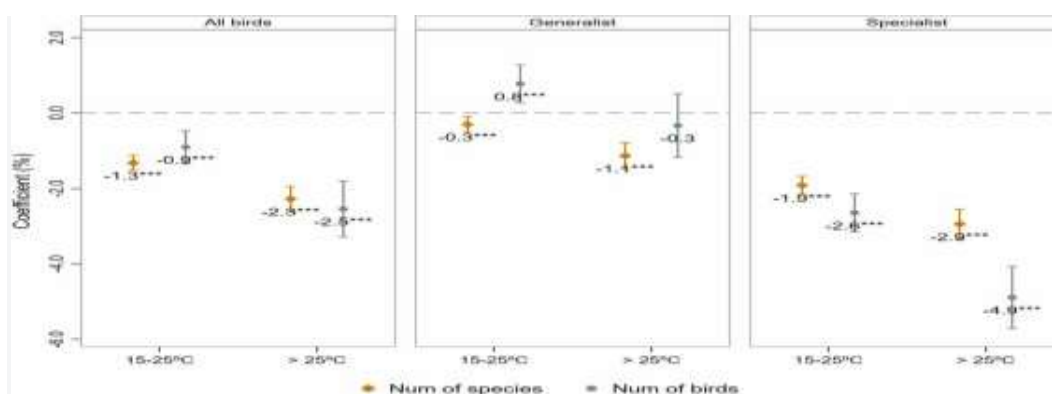


Fig:2 Temperature Effects on All Birds, Generalist Birds and Specialist Birds

5. Phenology of breeding in birds

The phenology of breeding in birds pertains to the timing of reproductive activities, such as nest construction, egg laying, hatching, and fledging, in relation to seasonal and environmental influences. This aspect is crucial to avian ecology, as reproductive success is closely associated with the availability of resources, including food and appropriate nesting locations. Typically, birds engage in breeding during times when environmental conditions are most favorable for nurturing their young. This period often aligns with the peak availability of food sources, particularly insects for insectivorous birds or seeds and berries for granivorous and frugivorous species. Various breeding patterns can be observed among birds inhabiting tropical regions or tropical oceanic islands. In locations where daily temperature and precipitation fluctuate minimally throughout the year, numerous bird species display continuous breeding behavior. However, studies of these species suggest that very few, if any, individuals breed continuously. Rather, each individual may experience periods of sexual inactivity lasting several months, while others within the population breed according to their own timelines. Additionally, some species residing in tropical regions synchronize their breeding with seasonal rainfall patterns and dry spells. For example, the reproduction of a community comprising 22 species of hummingbirds in lowland Costa Rica took place during the dry season, coinciding with a peak in the flowering of various plant species.

6. Energetics of the annual cycle of birds

The yearly cycles of birds seem to be inherently designed to ensure that breeding occurs during the most favorable season, which typically coincides with periods of mild temperatures and abundant food resources. The remaining stages of the annual cycle are structured in accordance with the breeding timetable, allowing the birds to be both physiologically and behaviorally prepared to mate in the appropriate location and at the optimal moment.

7. Timing of the annual cycle

Due to the fact that errors in the timing of breeding can lead to significant repercussions for reproductive success and overall fitness, natural selection has favored the utilization of the most dependable cues to signal the appropriate time of year and when to initiate physiological preparations (such as molting and fat accumulation) in advance of an event. Initial predictive cues (like photoperiod) offer a basic timing mechanism that can be influenced by other factors present on the breeding grounds (such as food availability, temperature, nesting site accessibility, snow cover, etc.) which can either hasten or postpone the actual breeding process. The long-term predictability of the environment where a species breeds dictates the extent to which secondary cues are employed and the potency of their effects. The annual cycles of birds residing either entirely or partially in middle to high latitudes are primarily regulated by the yearly variation in day length, in conjunction with an internal rhythm of photosensitivity observed in certain species. Although daily fluctuations in photoperiod do not seem to be the predominant environmental factor (Zeitgeber) governing

the annual cycle of some tropical species, the gonads of at least a few species have shown responsiveness to photoperiodic cues in controlled laboratory settings. Red Crossbills exhibit sensitivity to photoperiod and may utilize it to regulate their annual cycle; however, abundant food resources can trigger actual breeding at any point during the year. The annual cycles of numerous avian species inhabiting tropical areas, where photoperiod remains relatively constant throughout the year, are governed by circannual rhythms. In certain tropical regions, predictable rainfall patterns act as a timing mechanism that aligns the annual cycles of some species with optimal food availability.

8.1. Migration

Mistimed breeding can have severe consequences for reproductive success and overall fitness, which is why natural selection has favored reliance on the most reliable cues to determine the correct season and initiate physiological preparations—such as molting and fat accumulation—well in advance of breeding. Primary predictive cues, such as photoperiod (day length), provide a fundamental timing mechanism, which can then be modified by local factors at the breeding grounds, including food supply, temperature, nesting site availability, and snow cover. These secondary cues can either accelerate or delay breeding activity, and their influence depends largely on how predictable environmental conditions are in a species' breeding habitat.

For bird species living entirely or partially in temperate and polar latitudes, annual cycles are primarily regulated by seasonal changes in day length, combined with an internal rhythm of photosensitivity observed in some species. In contrast, while photoperiod changes are not always the dominant environmental cue (Zeitgeber) in many tropical species, laboratory studies have shown that the reproductive systems of at least a few tropical birds can respond to day length. For example, Red Crossbills exhibit photoperiod sensitivity, but abundant food can trigger breeding at virtually any time of year. In tropical regions, where day length is relatively constant, many species rely on circannual rhythms, and in some areas, predictable rainfall patterns serve as a key timing signal, aligning breeding with peak food availability.

Climate projections indicate that ptarmigan populations may decline by 25% in the 2040s, 44% in the 2050s, and 56% in the 2080s, depending on various influencing factors. Many researchers have long recorded the first arrival dates of birds at breeding sites; however, the reliability of these records can vary depending on population size and sampling frequency. Measuring variation in arrival dates within the population is just as important as recording the first arrival date when assessing whether a population is arriving earlier, later, or on schedule. For example, a 6-day advance in the first arrival date would be significant if the total arrival window for the population was 12 days, but far less meaningful if the window was 30 days. More comprehensive data are needed to understand the effects of early arrivals or late departures from summering grounds on breeding success and population sustainability.

Research on spring migration to northern Europe shows that many species are now arriving earlier. Additionally, in Central Europe, delayed autumn departures and earlier spring returns from wintering grounds—observed in at least 30 species—have been linked to climate change. Some previously sedentary populations have become partially migratory, while certain fully migratory species or populations have shifted to partial migration or even sedentary behavior. These rapid changes suggest that migration strategies can evolve quickly in response to environmental pressures, with traits being passed down to subsequent generations.

Breeding

As noted earlier, egg laying and raising offspring represent the most energy-intensive stages in the annual cycle of many bird species. Regardless of these high energy demands, sustained reproductive success is essential for species survival. Therefore, the projected effects of climate change on breeding could be devastating, potentially leading to species extinction. Current studies on the relationship between climate

change and breeding phenology have produced mixed results, largely due to differences among species, site-specific environmental conditions, and the varying intensity of climate change relative to historical adaptation patterns. Future research should expand beyond temperature and egg-laying data to also include variability in first-egg dates, food availability, clutch size, hatching success, fledgling numbers, and long-term changes in population size.

8.3. Mismatches between food availability and avian annual cycles

Discrepancies in breeding and food resources have been observed in thick-billed murres (*Uria lomvia*) nesting near Hudson Bay, Canada. Between 1988 and 2007, the breakup of sea ice has occurred 17 days earlier, coinciding with an earlier peak in food availability, defined as the date when the murre population reaches its annual maximum [21]. In contrast, the timing of egg laying has only advanced by 5 days, leading to an increased gap between the hatching date and the peak food availability. Consequently, nestling growth is hindered in years when the adult population peaks earlier than the hatching date

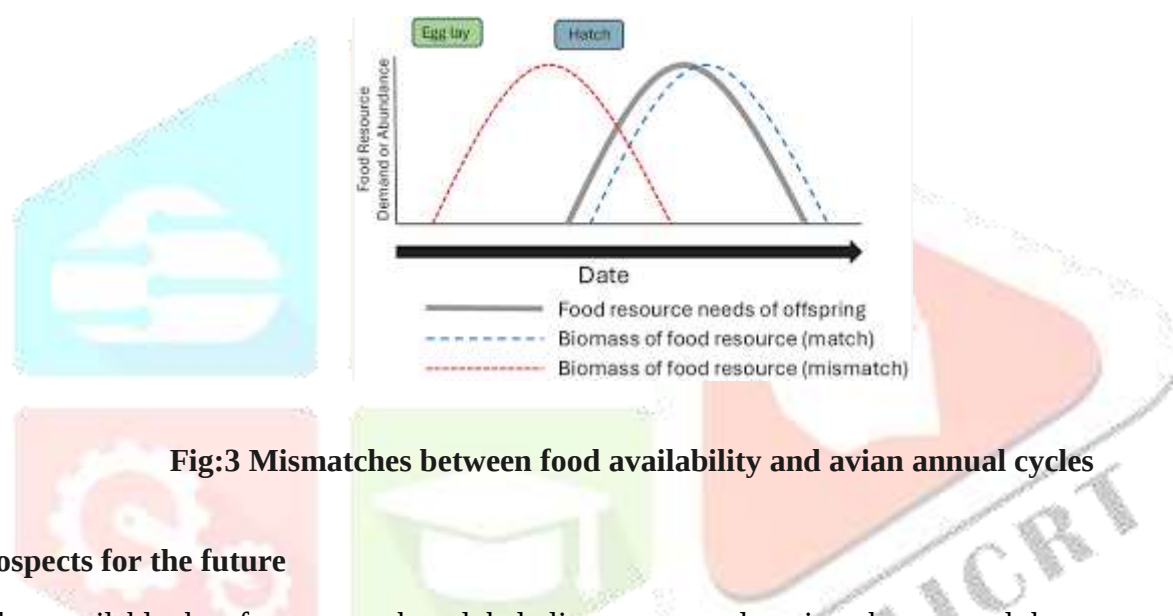


Fig:3 Mismatches between food availability and avian annual cycles

9. Prospects for the future

The data available thus far suggest that global climates are undergoing changes and that, to some extent, the annual cycles of certain avian species are adapting accordingly. While it may be premature to determine which species will thrive, face challenges, or potentially face extinction in the years ahead, some species might possess an advantage: Birds that breed in response to unpredictable food availability, such as red crossbills or zebra finches, along with non-migratory birds and short-distance migrants, may demonstrate the greatest resilience as future climates evolve and communities are restructured. Conversely, migratory birds that rely on internal biological clocks and fixed Zeitgebers, like photoperiod, may encounter significant difficulties in addressing the challenges posed by global climate change if they are unable to modify their timing mechanisms to align with new environmental conditions. Nevertheless, in all scenarios, food availability remains crucial: species that specialize in a limited variety of food types, particularly during their breeding season, may struggle to sustain population viability unless they can adapt to new food sources.

10. Conclusions and future directions

Ornithology has offered some of the most compelling examples of the effects of recent climate change on wildlife globally, yet we have merely begun to explore this topic. The area that has been studied the most, largely due to the availability of long-term datasets, is phenological change. The implications of such changes remain largely unexamined, but instances of phenological mismatching and phenological disjunction detrimental to the affected species have already been documented. One research domain that requires immediate focus is the intrinsic and extrinsic factors that may hinder adaptation to climate change. These

factors encompass: Lack of phenotypic/genotypic adaptability: species that cannot respond to climate change are likely to be the most susceptible. Dispersal ability: species with limited dispersal capabilities may struggle to migrate in response to shifts in their climatic environment, particularly when exacerbated by habitat fragmentation. Ecological specialization: swift environmental changes are expected to benefit generalist or adaptable species while posing risks to highly specialized species that thrive in specific ecological niches. Small population size: this will render species more susceptible to rapid stochastic changes, especially if climate variability increases as anticipated. Increased frequency of extreme events: populations can suffer significant declines due to extreme climatic occurrences, and a rise in their frequency may jeopardize long-term population viability. Habitat loss or degradation: climate change may impact the viability of the habitats utilized by birds, altering the timing and availability of their food sources and other essential resources. Large-scale agricultural transformations, including shifts in crop types and pesticide application (in response to changing pest populations), will be particularly significant for numerous bird species inhabiting human-altered environments. Changes in the distribution of other species: when species experience range expansion or contraction due to climate change, it may disrupt existing ecological balances. The potential for invasive and alien species to cause harmful effects is another significant aspect that must be taken into account: certain species that are presently harmless or restricted from establishing themselves in specific regions may alter their characteristics under modified environmental conditions.

While the intricacies of multi-trophic interactions represent crucial fields for investigation, considerable effort remains necessary to comprehend the influence of climate change on the population dynamics of individual species. It is important to note that climate variability can impact populations in a density-independent fashion, but it may also influence the intensity of density dependence that governs a population. Population modeling, akin to the groundbreaking work previously conducted, is urgently required so that we can advance beyond studies focused on single parameters and start to grasp the complexities of the interactions among various elements of a species' demography.

References

1. Alley R. B., Mayewski P. A., Sowers T., Stuiver M., Taylor K. C., Clark P. U. 1997 *Holocene climatic instability: a prominent, widespread event 8200 yr ago*. *Geology* 25, 483–486 ([doi:10.1130/0091-7613\(1997\)025<0483:HCIAPW>2.3.CO;2](https://doi.org/10.1130/0091-7613(1997)025<0483:HCIAPW>2.3.CO;2)) [[Google Scholar](#)]
2. Baines D., Wilson I. A., Beeley G. 1996 *Timing of breeding in black grouse *Tetrao tetrix* and capercaillie *Tetrao urogallus* and distribution of insect food for the chicks*. *Ibis* 138, 181–187 ([doi:10.1111/j.1474-919X.1996.tb04327.x](https://doi.org/10.1111/j.1474-919X.1996.tb04327.x)) [[Google Scholar](#)]
3. Barbraud C., Weimerskirch H. 2006 *Antarctic birds breed later in response to climate change*. *Proc. Natl Acad. Sci. USA* 106, 6248–6251 ([doi:10.1073/pnas.0510397103](https://doi.org/10.1073/pnas.0510397103)) [[DOI](#)] [[PMC free article](#)] [[PubMed](#)] [[Google Scholar](#)]
4. Birks H. H., Ammann B. 2000 *Two terrestrial records of rapid climatic change during the glacial–Holocene transition (14,000–9,000 calendar years B.P.) from Europe*. *Proc. Natl Acad. Sci. USA* 97, 1390–1394 ([doi:10.1073/pnas.97.4.1390](https://doi.org/10.1073/pnas.97.4.1390)) [[DOI](#)] [[PMC free article](#)] [[PubMed](#)] [[Google Scholar](#)]
5. Böhning-Gaese K., Lemoine N. 2004 *Importance of climate change for ranges, communities and conservation of birds*. *Adv. Ecol. Res.* 35, 211–236 ([doi:10.1016/S0065.2504\(04\)35010-5](https://doi.org/10.1016/S0065.2504(04)35010-5)) [[Google Scholar](#)]
6. Both C., Visser M. E. 2001 *Adjustment to climate change is constrained by arrival date in a long-distance migrant bird*. *Nature* 411, 296–298 ([doi:10.1038/35077063](https://doi.org/10.1038/35077063)) [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]

7. Carey C., Bradford D. F., Brunner J. F., Collins J. P., Davidson E. W., Longcore J. E., Ouellet M., Pessier A. P., Schock D. M. 2003 Biotic factors in amphibian declines. In *Multiple stressors and declining amphibian populations: evaluating cause and effect* (eds Linder G., Sparling D. W., Krest S. K.), pp. 153–208 Boca Raton, FL: Society of Environmental Toxicology and Chemistry [[Google Scholar](#)]
8. Coppack T., Both C. 2002 Predicting life-cycle adaptation of migratory birds to global climate change. *Ardea* 90, 369–378 [[Google Scholar](#)]
9. Cotton P. A. 2003 Avian migration phenology and global climate change. *Proc. Natl Acad. Sci. USA* 100, 12 219–12 222 ([doi:10.1073/pnas.1930548100](https://doi.org/10.1073/pnas.1930548100)) [[DOI](#)] [[PMC free article](#)] [[PubMed](#)] [[Google Scholar](#)]
10. Crick H. Q. P., Sparks T. H. 1999 Climate change related to egg-laying trends. *Nature* 399, 423 ([doi:10.1038/20839](https://doi.org/10.1038/20839)) [[Google Scholar](#)]
11. Daan S., Dijkstra C., Drent R., Meijer T. 1988 Food supply and the annual timing of avian reproduction. In *Acta XIX Congressus Internationalis Ornithologici* (ed. Ouellet H.), pp. 392–407 Ottawa, ON: University of Ottawa Press [[Google Scholar](#)]
12. Davis M. B., Shaw R. G. 2001 Range shifts and adaptive responses to Quaternary climate change. *Science* 292, 673–679 ([doi:10.1126/science.292.5517.673](https://doi.org/10.1126/science.292.5517.673)) [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
13. Erwin D. H. 2001 Lessons from the past: biotic recoveries from mass extinctions. *Proc. Natl Acad. Sci. USA* 98, 5399–5403 ([doi:10.1073/pnas.091092698](https://doi.org/10.1073/pnas.091092698)) [[DOI](#)] [[PMC free article](#)] [[PubMed](#)] [[Google Scholar](#)]
14. Foster M. P. 1974 A model to explain molt-breeding overlap and clutch size in some tropical birds. *Evolution* 28, 182–190 ([doi:10.2307/2407321](https://doi.org/10.2307/2407321)) [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
15. Gaston A. J., Gilchrist H. G., Mallory M. L., Smith P. A. 2009 Changes in seasonal event, peak food availability and consequent breeding adjustment in a marine bird: a case of progressive mismatching. *Condor* 111, 111–119 ([doi:10.1525/cond.2009.080077](https://doi.org/10.1525/cond.2009.080077)) [[Google Scholar](#)]
16. Gwinner E. 1977 Circannual rhythms in bird migration. *Ann. Rev. Ecol. Syst.* 8, 381–405 ([doi:10.1146/annurev.es.08.110177.002121](https://doi.org/10.1146/annurev.es.08.110177.002121)) [[Google Scholar](#)]
17. Hahn T. P. 1995 Integration of photoperiodic and food cues to time changes in reproductive physiology by an opportunistic breeder, the red crossbill, *Loxia curvirostra* (Aves: Carduelinae). *J. Exp. Zool.* 272, 213–226 ([doi:10.1002/jez.1402720306](https://doi.org/10.1002/jez.1402720306)) [[Google Scholar](#)]
18. Møller A. P., Fiedler W., Berthold P. (eds) 2004 *Birds and climate change. Advances in ecological research*, vol. 35. Amsterdam, The Netherlands: Elsevier Academic Press [[Google Scholar](#)]
19. Parmesan C., Yohe G. 2003 A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 42, 37–42 ([doi:10.1038/nature01286](https://doi.org/10.1038/nature01286)) [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
20. Perrins C. M. 1970 The timing of birds' breeding seasons. *Ibis* 112, 242–255 ([doi:10.1111/j.1474-919X.1970.tb00096.x](https://doi.org/10.1111/j.1474-919X.1970.tb00096.x)) [[Google Scholar](#)]
21. Raup D. M. 1991 A kill curve for phanerozoic marine species. *Paleobiology* 17, 37–48 [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]
22. Root T., Price J. T., Hall K. R., Schneider S. H., Rosenzweig Pounds J. H. 2003 Fingerprints of global warming on wild animals and plants. *Nature* 421, 57–60 ([doi:10.1038/nature01333](https://doi.org/10.1038/nature01333)) [[DOI](#)] [[PubMed](#)] [[Google Scholar](#)]

23. Root T. L., MacMynowski D. P., Mastrandrea M. D., Schneider S. H. 2005 Human-modified temperatures induce species changes: joint attribution. *Proc. Natl Acad. Sci. USA* 102, 7465–7469 ([doi:10.1073/pnas.0502286102](https://doi.org/10.1073/pnas.0502286102)) [DOI] [PMC free article] [PubMed] [Google Scholar]
24. Taylor K. 1999 Rapid climate change. *Am. Sci.* 87, 320–327 [Google Scholar]
25. Thomas D. W., Blondel J., Perret P., Lambrechts M. M., Speakman J. R. 2001 Energetic and fitness costs of mismatching resource supply and demand in seasonally breeding birds. *Science* 291, 2598–2600 ([doi:10.1126/science.1057487](https://doi.org/10.1126/science.1057487)) [DOI] [PubMed] [Google Scholar]
26. Thomas C. D., et al. 2004 Extinction risk from climate change. *Nature* 427, 145–148 ([doi:10.1038/nature02121](https://doi.org/10.1038/nature02121)) [DOI] [PubMed] [Google Scholar]
27. Torti V. M., Dunn P. O. 2005 Variable effects of climate change on six species of North American birds. *Oecologia* 145, 486–495 ([doi:10.1007/s00442-005-0175-4](https://doi.org/10.1007/s00442-005-0175-4)) [DOI] [PubMed] [Google Scholar]
28. Verboven N., Visser M. E. 1998 Seasonal variation in local recruitment of great tits: the importance of being early. *Oikos* 81, 511–524 ([doi:10.2307/3546771](https://doi.org/10.2307/3546771)) [Google Scholar]
29. Walsberg G. E. 1983 Avian ecological energetics. In *Avian biology*, vol. VII (eds Farner D. S., King J. R.), pp. 161–220 New York, NY: Academic Press [Google Scholar]
30. Weatherhead P. J. 2005 Effects of climate variation on timing of nesting, reproductive success and offspring sex ratios of red-winged blackbirds. *Oecologia* 144, 168–175 ([doi:10.1007/s00442-005-0009-4](https://doi.org/10.1007/s00442-005-0009-4)) [DOI] [PubMed] [Google Scholar]
31. Woodhouse C. A., Overpeck J. T. 1998 2000 years of drought variability in the Central United States. *Bull. Am. Meteorol. Soc.* 79, 2693–2714 ([doi:10.1175/1520-0477\(1998\)079<2693:YODVIT>2.0.CO;2](https://doi.org/10.1175/1520-0477(1998)079<2693:YODVIT>2.0.CO;2)) [Google Scholar]
32. Zaan R. 1996 *The zebra finch: synthesis of field and laboratory studies*. Oxford, UK: Oxford University Press [Google Scholar]
33. Zachos J., Pagani M., Sloan L., Thomas E., Billups K. 2001 Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science* 292, 686–687 ([doi:10.1126/science.1059412](https://doi.org/10.1126/science.1059412)) [DOI] [PubMed] [Google Scholar]