Journal of Animal Environment
(E-ISSN 2717-1396, ISSN 2717-1388)
Journal homepage: https://aejournals.org/

Original Research Paper/Review Paper

Impact of Climate Variability on Wildlife Migration Patterns and Seasonal Adaptation Strategies in Changing Habitats

Dr. Jainish Roy[1], Dr. Rajesh Sehgal[2], Rajender Sharma[3]*

[1*] *Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.*
Email: ku.jainishroy@kalingauniversity.ac.in, ORCID: https://orcid.org/0009-0003-7116-9137
[2] *Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.*
Email: ku.rajeshsehgal@kalingauniversity.ac.in, ORCID: https://orcid.org/0009-0002-0344-403X
[3] *Assistant Professor, New Delhi Institute of Management, New Delhi, India.*
Email: rajender.sharma@ndimdelhi.org, ORCID: https://orcid.org/0009-0009-5063-5876

Key Words
Climate variability, Wildlife migration, Seasonal adaptation, Phenological mismatch, Animal movement ecology, Climate change impacts, Migratory species, Ecological responses, Habitat change, Conservation biology.

Abstract
Migration of migratory species is coordinated with consistent seasonal signals such as temperature or vegetation green-up events in order to coordinate movement among breeding, stopover, and non-breeding grounds. Climate variability is increasingly creating mismatches between environmental cues and migration timing in terms of speed that is exceeding the capacity of many organisms to adapt, thereby creating a phenomenon of phenological mismatch between migrant species and their resource availability. The present paper provides an analysis of evidence available from global meta-analysis and long-term studies of animal movements in order to estimate the degree of climatic changes on migration timing across different species, the adaptation mechanisms used by organisms, and the ecological impacts when adaptation is unsuccessful. Mammals, birds, and invertebrates have shown a rate of migration advance of about 2-5 days per decade; however, there is a significant variability depending on the taxonomic group, migration distance, and hemisphere. Adaptation due to behavioral flexibility is the main reason for phenological adjustments while even adaptable organisms face difficulties adapting to resource pulses shifting quicker than the migration behavior itself.

* Corresponding Author's email: ku.jainishroy@kalingauniversity.ac.in
Received: 25th May, 2026; Revised: 6th June, 2026; Accepted: 8th June, 2026; Available Online: 07th August, 2026
(DOI): 10.70102/AEJ.2026.18.3s.03

Introduction

Migration has been one of the most prominent adaptations to seasonally varying environments where the species can benefit from resource pulses, escape unfavorable environments, and make use of the limited breeding habitat that is only available during certain times of the year. The time when animals migrate has been known to be well-coordinated with some predictable changes related to seasons such as the length of the day, temperature, and seasonality in the growth of vegetation. Climate change brought about by human activities is disrupting these changes in different ways spatially, ecologically, and seasonally, hence creating concerns regarding the mismatch of arrival of migratory species at the breeding and stopover sites with respect to the resource requirements (Cohen et al., 2018; Aikens et al., 2020). Such mismatches have been the most widely reported biological impacts of climate change across continents and across all kinds of species including birds, mammals, fish, and invertebrates. This review is an attempt to summarize what we know about how climate change is affecting the timing of migration and what adaptation strategies migratory wildlife is adopting (Kubelka et al., 2022; Ortega et al., 2023).

Methods

This literature review consolidates results from meta-analysis studies carried out on a global scale and regionally, complemented by long-term observation data on individually studied migratory populations. References have been made from peer-reviewed studies providing quantification of shifts in either migration and/or breeding phenology in terms of number of days shifted either per decade or per one degree of warming (Usui et al., 2017). In cases when the comparable measures of shift could be found within each study, we compared the magnitude of shift across taxa and hemispheres as summarized below (Chambers et al., 2013).

Results

Overall, in the studies reviewed, there is an observed trend for migratory and seasonal wildlife to exhibit earlier spring phenology on a global scale, although the degree of advance varies widely according to different taxa, geographical regions, and life history strategies. Global meta-analyses of over 1,000 time series have indicated that the advance in animal phenology is by an average rate of about 2.88 days per decade; however, the level of the response varied significantly depending on the taxonomy and not the trophic group (Cohen et al., 2018).

Small-bodied non-insects invertebrates exhibited one of the fastest levels of advance of almost 4.93 days per decade, whereas birds demonstrated relatively moderate changes of about 2.1 days per decade in spring migration timing for 413 species and five continents (Usui et al., 2017). Additionally, regional differences demonstrate an unevenness of advance between the hemispheres; specifically, taxa from the Southern Hemisphere exhibited a rate of advance of 4.2 days per decade, which is higher than the advance observed for Northern Hemisphere terrestrial taxa of about 2.8 days per decade in a similar period, even though the Southern

* Corresponding Author’s email: ku.jainishroy@kalingauniversity.ac.in
Received: 25th May, 2026; Revised: 6th June, 2026; Accepted: 8th June, 2026; Available Online: 07th August, 2026
(DOI): 10.70102/AEJ.2026.18.3s.03

Hemisphere data set was smaller and geographically confined (Chambers et al., 2013). The effect of climatic variability on migration for large migratory herbivores that synchronize their movements according to seasonal green-up peaks of plant growth and not through seasonal cues is seen through compression of the availability period of their resource and not changes in the average period of occurrence of this event; drought conditions were shown to reduce the green-up period of spring for mule deer migration areas by about two and a half weeks – which is about half the normal green-up period under non-drought conditions – without impeding their ability to follow the green wave (Aikens et al., 2020).

Table 1: Reported Magnitude of Climate-Driven Phenological Shift in Migration Timing Across Taxonomic Groups and Regions

Taxonomic Group	**Mean Phenological Shift**	**Geographic Scope**	**Primary Data Source**
All animal taxa (pooled)	2.88 days/decade earlier	Global	Cohen et al., (2018)
Non-insect invertebrates	4.93 days/decade earlier	Global	Cohen et al., (2018)
Birds (spring migration)	2.1 days/decade earlier	5 continents, 413 species	Usui et al., (2017)
Southern Hemisphere taxa (pooled)	4.2 days/decade earlier	Australasia, S. America, Antarctic	Chambers et al., (2013)
Northern Hemisphere terrestrial taxa	2.8 days/decade earlier	Europe, N. America, Asia	Chambers et al., (2013)
Migratory ungulates (green-up tracking)	~2.5-week reduction in green-wave duration under drought	Western North America	Aikens et al., (2020)

Two trends emerge from the comparison. The first is that the speed of phenological advancement is not consistent between different taxa, whereby smaller bodied, lower trophic level species advance more quickly than larger, longer living vertebrate species, leading to the potential for asynchrony between the migrants and the resource or species with which they interact through phenology. Second, variability between regions and taxa is just as great, if not greater than the global average phenological advancement, implying that the rate of phenological advance underestimates the variability experienced by migratory species.

Mechanisms of Seasonal Adaptation

Behavioral Plasticity in Timing

Behavioral plasticity is currently the predominant means by which migratory species have adapted to changing climatic cues, as the timing of departure, arrival, or rate of movement each year can be altered according to local temperature or vegetation cues without requiring an underlying genetic shift. There is still very little evidence of microevolutionary, genetically driven changes in migration or breeding phenology. The majority of the observed advancement in migration or breeding phenology in birds is better explained by individual-level behavioral adaptation than evolutionary adaptation. Behavioral adaptation provides the means by which numerous species are able to adapt in part to annual differences in springtime conditions; however, it is insufficient for tracking directional changes in the climate.

Route and Speed Compensation

Adjustment of migratory departure dates is not the only way for some species to deal with mismatches. Indeed, migrants may adjust their pace or the length of stopovers in order to synchronize with the arrival of green-up during migration. Studies of migratory mule deer have demonstrated that those which started migration out of sync with the green wave, being either too early or too late, increased their pace and reduced the stopover length in order to catch up with the resource wave. The late migrants migrated about two and a half times faster and spent less time at stopovers compared to the early ones.

Range and Route Shifts

Aside from changes in timing, migratory animals are changing the geography of migration, by moving their breeding grounds northward or upward, as well as in some cases foregoing their traditional long migrations and instead remaining residents in locations that have experienced milder winters than before, which is feasible due to such warming conditions. The range changes occurring in migratory animals combine in complicated ways with timing changes, insofar as populations changing their breeding grounds can also change their environment in terms of temperature signals, food availability, and predation/competition pressures.

Limits of Adaptive Capacity

Notwithstanding these adaptations, there is proof that the rate of phenological shifts in resource availability exceeds the ability of migrating behavior to keep up with it in many species. Species of birds migrating over long distances, dependent on endogenous cues or photoperiodic cues to depart from the areas where they do not breed, far away from their final destination, advance less phenologically than short-distance migratory species, which can use local cues to adjust their timing of migration, putting long-distance migrants more at risk of mismatch (Usui et al., 2017). Besides phenological mismatch itself, migratory species breeding in northern latitudes experience multiple other stresses, such as being increasingly exposed to new pathogens, parasites, and predators moving polewards due to climate change, which may result in a loss of some evolutionary benefits of long-distance migrations (Kubelka et al., 2022).

Ecological Consequences of Incomplete Adaptation

Trophic Mismatch and Reproductive Costs

In cases where the migratory schedule falls behind changing phenology of resource availability, the mismatch imposes fitness costs. Evidence from studies on insectivorous bird species suggests that brood survival and fledging success decrease when the period of peak nestling feeding demands no longer matches the period of peak availability of prey species, even if the birds' breeding phenology is shifted forward substantially relative to the past. As illustrated in table 1 below, different species experience different rates of phenological change and the differences between these rates are not random, so some are more susceptible to temporal mismatches caused by behavioral inflexibility than others (Cohen et al., 2018).

Interactions with Non-Climatic Stressors

However, changes in phenology caused by climate change almost never occur in isolation. Birds coming to breed in the high latitudes now face a series of additional threats other than climatic ones, which may increase the possibility of mismatch for migratory birds. These include emerging pathogens and parasites whose range has been extended polewards in response to warming, as well as changes in the community of predators as the range of generalist predators moves to colder areas. These additional threats ensure that even those populations of migratory species that can adjust phenology to one of the resources remain vulnerable because of the overall effect of both climatic and non-climatic stressors (Kubelka et al., 2022).

Population-Level and Community Consequences

In terms of the population, the phenological mismatch has been found to be associated with a reduction in population size of the migratory birds over a longer period of time, especially for those long-distance migrants that have shown least ability to compensate for the mismatch in relation to their breeding grounds' changing environment (Kubelka et al., 2022; Usui et al., 2017). In terms of communities, a disparity in phenological responses between different species such as faster advance of prey than predators or faster advance of the plant compared to their pollinator/herbivore, can restructure food web dynamics even when there is no extinction of any single species. In case of the migratory ungulates, a narrowing window of green-up periods due to drought may reduce the overall energy gain from migration period, regardless of tracking the green wave period successfully (Aikens et al., 2020).

Discussion

In sum, the current body of evidence shows that the response of migratory wildlife to the changing seasons occurs via behavioral mechanisms, not evolutionary mechanisms, and that such behavioral plasticity is large but limited, and is taxonomically and geographically variable according to migratory distance. Since small-bodied, lower-trophic level taxa tend to adapt faster than larger-bodied vertebrates, it can be surmised that trophic mismatching will prove a more pressing problem resulting from climate variability than decline, since species will move out of sync with their partners even as each respond to environmental signals in a way (Cohen et al., 2018). The pronounced hemispheric disparity in adaptation rates means that research and conservation frameworks established using birds from the Northern Hemisphere's temperate zones may prove inadequate when applied elsewhere, and that increased observation in the Southern Hemisphere and among non-avian taxa must take place in order to predict mismatch risks (Chambers et al., 2013). In large herbivorous migrators, according to ungulate studies, the climate variability effects may actually result in compression rather than shifting of the periods when resources are available, which is a unique adaptation problem that the time adaptation cannot solve entirely but within-migration behavioral changes do offer partial adaptability (Aikens et al., 2020; Ortega et al., 2023). Overall, all these results indicate the future where some migratory species would still be adaptive enough to survive the climate variability effects, whereas others – especially long-distance specialists relying on fixed-time cues – would encounter ever-growing mismatch issues.

Conclusion

Climate variability is causing significant changes in the schedules, flight paths, and resource tracking behavior of migratory species around the globe. The phenological advancement due to this process averages 5-6 days per decade, although there is considerable variation depending on the type of organism involved, its place within the food chain, location in the Northern or Southern Hemisphere, and migratory strategy. While behavioral adaptability in the form of flexible departure times and in-flight speed adjustments does allow many migratory species to compensate somewhat for changing seasonal cues, this capability seems to have limits and may be inadequate for long-distance migrations or species requiring a certain schedule based on physiological cues.

References

[1] Aikens, Ellen O., Kevin L. Monteith, Jerod A. Merkle, Samantha PH Dwinnell, Gary L. Fralick, and Matthew J. Kauffman. "Drought reshuffles plant phenology and reduces the foraging benefit of green-wave surfing for a migratory ungulate." *Global change biology* 26, no. 8 (2020): 4215-4225. https://doi.org/10.1111/gcb.15169

[2] Chambers, Lynda E., Res Altwegg, Christophe Barbraud, Phoebe Barnard, Linda J. Beaumont, Robert JM Crawford, Joel M. Durant et al. "Phenological changes in the southern hemisphere." *PloS one* 8, no. 10 (2013): e75514.

[3] Cohen, Jeremy M., Marc J. Lajeunesse, and Jason R. Rohr. "A global synthesis of animal phenological responses to climate change." *Nature climate change* 8, no. 3 (2018): 224-228. https://doi.org/10.1038/s41558-018-0067-3

[4] Kubelka, V., Sandercock, B. K., Székely, T., & Freckleton, R. P. (2022). Animal migration to northern latitudes: environmental changes and increasing threats. Trends in ecology & evolution, 37(1), 30-41.

https://doi.org/10.1371/journal.pone.0075514

[5] Ortega, Anna C., Ellen O. Aikens, Jerod A. Merkle, Kevin L. Monteith, and Matthew J. Kauffman. "Migrating mule deer compensate en route for phenological mismatches." *Nature Communications* 14, no. 1 (2023): 2008. https://doi.org/10.1038/s41467-023-37750-z

[6] Usui, Takuji, Stuart HM Butchart, and Albert B. Phillimore. "Temporal shifts and temperature sensitivity of avian spring migratory phenology: A phylogenetic meta-analysis." *Journal of Animal Ecology* 86, no. 2 (2017): 250-261. https://doi.org/10.1111/1365-2656.12612