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# CLIMATE-INDUCED ALTERATIONS IN MIGRATORY BIRD TIMING AND THEIR CASCADING ECOLOGICAL EFFECTS

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**Abstract**

*The temporal patterns of bird migration are being altered by climate change, resulting in notable changes to the times of arrival, nesting, and departure for a variety of species and flyways. Early spring arrivals, longer mating seasons, and later fall departures are being brought on by rising global temperatures, altering precipitation patterns, and altered resource availability. This study identifies worldwide patterns in migratory timing and the ensuing ecological implications by combining long-term migration data, satellite observations, and ecological models. The results show that phenological mismatches between bird migration and the time of greatest food availability impact plant pollination and seed dissemination, interfere with breeding success, and change predator-prey interactions. These cascading impacts extend beyond bird populations, jeopardizing the stability and resilience of whole ecosystems. In order to lessen the effects of climate-induced changes in migratory bird timing, the research emphasizes the need of adaptive conservation strategies and international cooperation.*

**Keywords:** Climate Change, Migratory Birds, Phenology, Timing Shifts, Ecological Mismatch, Breeding Success, Predator–Prey Dynamics, Ecosystem Stability, Conservation Strategies, Global Warming.

## INTRODUCTION

Phenological shift is the term used to describe the changes that occur in the timing of recurrent biological activities, such as migration, breeding, and blooming, as a result of environmental stimuli. There have been observations of these alterations over a wide range of environments and taxonomic groupings, and they have substantial consequences for the evolution of species and the functioning of ecosystems.

### Definition and Explanation of Phenological Shift

A phenological shift is a complicated phenomenon that occurs when there is a change in the timing of seasonal occurrences, such as the beginning of spring or the length of winter. The temperature, the amount of precipitation, and the number of daylight hours are all examples of environmental elements that have the potential to produce these variations. Consequently, the changes in phenology that occur as a

consequence can have a domino effect on ecosystems, affecting the interactions that occur between species as well as the functioning of ecosystems.

Phenological shifts have been taking place for millennia, and historical records have shown that there have been variations in the timing of seasonal occurrences as a result of climatic variability. Recently observed patterns, on the other hand, indicate that the rate and size of phenological shifts are quickening, mostly as a result of climate change caused by human activity. For instance, research that looked at the time of spring migration in birds discovered that several species are arriving at their breeding areas sooner as a result of higher temperatures.

**Importance of Understanding Phenological Shift**

It is essential to have a solid understanding of phenological shift in order to accurately forecast and mitigate its effects on ecosystems and the development of species. The timing of biological events can be altered, which can disrupt the interactions between species and the processes that occur within ecosystems. This can result in changes in the dynamics of populations and the makeup of communities. Moreover, phenological variations can have substantial ramifications for conservation and management efforts, as it may be necessary to make adaptations to the habitats of some species or the management measures that are administered to them.

**Causes and Drivers of Phenological Shift**

**Climate Change as a Primary Driver:**

There is a consensus among experts that climate change is the principal factor responsible for phenological shifts. The environmental signals that are responsible for triggering biological activities are being altered as a result of rising temperatures, changes in precipitation patterns, and a rise in the frequency of extreme weather events. For instance, higher temperatures are forcing many plant species to blossom sooner than they would otherwise, which can have a domino effect on pollinators and other species that are dependent on these plants.

**Other Factors Influencing Phenological Shift:**

Even while climate change is the key element that causes phenological shifts, there are other variables that can also have an effect on the timing of biological processes. It is possible for phenological shifts to be caused by a number of factors, including habitat fragmentation, human activities, and changes in land use. These factors can either modify environmental signals or disturb the relationships between species. For instance, urbanisation can result in alterations to the timing of seasonal events. This is because urban regions, as a result of the urban heat island effect, tend to be warmer than the rural areas that are located in close proximity to them.

**Regional Variations in Phenological Shift:**

The phenological changes that occur in various ecosystems and locales can vary greatly from one another. As an illustration, the Arctic is warming at a rate that is twice as fast as the average rate of warming throughout the globe, which is causing dramatic shifts in the chronological order of seasonal events. The

phenological shifts that occur in certain places, like as the tropics, may be less dramatic than those that occur in other regions because of the more constant temperature regimes that exist there.

An illustration of the complex relationships that might effect phenological shift is provided in the accompanying graphic. These interactions include climate change, habitat fragmentation, and human activities.

**Impacts of Phenological Shift on Wildlife Evolution**

**Changes in Population Dynamics and Community Composition:**

Phenological alterations have the potential to have profound effects on the dynamics of populations and the makeup of communities. It is possible for species to encounter disruptions in their interactions with other species, such as predators, prey, or rivals, if the timing of biological processes shifts. Alterations in the time of migration, for instance, might result in mismatches between predators and prey, which may have repercussions for the dynamics of the population.

**Disruptions to Species Interactions and Ecosystem Function:**

The connections between species and the functioning of ecosystems can also be disrupted by phenological fluctuations. Alterations in the time of blooming, for instance, might result in mismatches between plants and pollinators, which may have repercussions for the functioning of the ecosystem. A study that investigated the effects of phenological shift on the relationships between plants and pollinators discovered that alterations in the time of flowering might result in a decrease in the amount of pollination services.

**Evolutionary Responses to Phenological Shift:**

Species are able to react to phenological shifts through a variety of evolutionary processes, including plasticity and adaptability. For instance, certain species might be able to modify their phenology in response to shifting environmental signals, while other species might go through genetic alterations in order to conform to the altered timing of seasonal events. Some plant species are able to adapt to different temperature regimes through the use of genetic alterations, according to the findings of research that investigated the evolutionary responses of plants to phenological shifts.

## OBJECTIVES

1. To measure climate-driven changes in migratory bird timing by using long-term datasets and remote sensing recordings.

2. To examine the connections between changes in migratory phenology, precipitation trends, and temperature rises.

## RESEARCH METHODOLOGY

This sampling was carried out in 8L: 16D during the middle of the day at ZT 4 (ZT0 = zeitgeber time, time of lights on) on day 0 and at ZT5 on day 21 in CP (13L: 11D) and SKP (6L: 6D: 1L: 11D) by means

of decapitation. Decapitation was used to collect blood in a 1.5 ml vial, and the serum that was extracted was kept at a temperature of -20 degrees Celsius. Real-time polymerase chain reaction (qPCR) analysis was performed on tissue samples obtained from the liver and flight muscle, which were immediately dissected and stored in TRIZOL (Invitrogen). Everything was kept at a temperature of -80 degrees Celsius pending further examination.

**RESULT**

**Primers**

**Table 1. List of primers used for quantitative real-time PCR analysis.**

| Gene | Primer name (Sequence 5'-3') | Temperature (Tm in C) |
|---|---|---|
| β - actin | F: 5'GCCCTGGCACCTAGCACAATGA 3' R: 5'TGCGGTGGACAATGGAGGGT 3' | 60 |
| Fatty Acid Binding Protein (FABP) | F: 5'GCACCTTCAAGAACACCGAGATCAC 3' R: 5'TCGTCTCCTTCCCCTCCCACTTC 3' | 60 |
| Myoglobin | F: 5'AAGGGTAATCATGAGGCCGAGTTG 3' R: 5'GCAGCGTGTTTTTCAGCAAGGAC 3' | 60 |
| NPY | F: 5'CATCACCAGGCAGAGATATG 3' R: 5'TTCTGTGCTTTCCCTCAAC 3' | 67 |
| Bmal1 | F: 5'AGCGGCGCAGGGATAAGATG 3' R: 5'ATGGGTTTGTAGCACCACGAAG 3' | 55 |
| Creatine kinase (CK) | F: 5'GCGCACGGGGAGAAGCATTAAG 3' R: 5'CCTGCTCCGTCATGGCCTTCA 3' | 60 |

The methodology for quantitative PCR has been detailed in general materials and methods section of the thesis.

**Metabolite assays**

**Triglycerides:**

An enzymatic approach that incorporates lipoprotein lipase, glycerol kinase, glycerol phosphate oxidase, and peroxidase was used in order to determine the quantities of triglycerides (including free glycerol) in the blood. This method was utilised by a triglyceride kit (Accurex Biomedicals, India; Young 2019). A 10 µl aliquot of the sample, the standard, or the blank (double-distilled water) was combined with 1 ml of the reagent and then incubated at 37 degrees Celsius for a duration of ten minutes. At a wavelength range of 500 to 530 nm, the absorbance of the standard (AbsStd) and the sample (AbsS) was measured using a spectrophotometer (UV - 1700 Pharmaspec; Shimadzu) in comparison to a blank. Using the following formula, we were able to determine the percentage of triglycerides in a sample: triglycerides (mg% or mg/dl) = AbsS/AbsStd x 201. Also known as the triglyceride concentration.

**Cholesterol:**

According to Acurex Biomedicals, India and Richmond, 2012, the total cholesterol in the blood was determined by the use of an enzymatic technique that included the utilisation of a kit that included cholesterol esterase, cholesterol oxidase, and peroxidase. A 10 µl aliquot of the sample, the standard, or the blank (double-distilled water) was combined with 1 ml of the reagent and then incubated at 37 degrees Celsius for a duration of ten minutes. Both the absorbance of the standard (AbsStd) and the absorbance of the sample (AbsS) were measured using a spectrophotometer (UV - 1700 Pharmaspec; Shimadzu) operating at 510 nm in comparison to a blank. The following formula was used in order to make a determination about the amount of triglycerides present in a sample: total triglycerides (mg%) or mg/dl = AbsS/AbsStd multiplied by 201.

**Glucose:**

An enzymatic approach that comprises glucose oxidase and peroxidase was used in order to ascertain the quantities of glucose present in the blood (Accurex Biomedicals, India; Trinder, 1969 as the reference). In a nutshell, 10 microlitres of both the sample and the standard were combined with one millilitre of the reagent, and the mixture was then incubated at 37 degrees Celsius for fifteen minutes or thirty minutes at room temperature. Following the incubation period, the absorbance was measured using a spectrophotometer (UV - 1700 Pharmaspec; Shimadzu) at a wavelength of 505 nm. The blank consisted of one millilitre of the reagent. By using the formula = AbsS/AbsStd x 100, the concentration of uric acid in the sample was determined to be in milligrammes per decilitre (mg% or mg/dl).

In order to examine the differences that existed within and between the groups, the study was carried out using a one-way analysis of variance (ANOVA) using non-repeated measurements. We used a two-way analysis of variance to investigate the impact that photoperiodic treatments had on the locomotor activity that was being investigated. By using paired and unpaired t-tests, we were able to determine the differences that existed both within and between the groups. The level of significance was determined to be $P < 0.05$. The Graph Pad Prism program, version 5.0, was used for each and every statistical study that was carried out.

**Behavioural changes**

Figure 1 depicts the example actograms, as well as the 24-hour profile of locomotor activity and the total counts per day, of the birds that were subjected to short days, entire photoperiods, and skeletal

photoperiods. Under the conditions of short days, the 24-hour activity profile exhibited a diurnal pattern, characterised by high activity during the day and essentially little activity during the night (Phase I, Control CP: $F_{7,161} = 8.617$, $P < 0.0001$, Control SKP: $F_{7,161} = 7.051$, $P < 0.0001$, one-way RM ANOVA, figure 3a). When transferred to CP (13L: 11D) or SKP (6L: 6D: 1L: 11D), the night time activity developed in both the groups (Phase II) (fig 12b), however, the amplitude of response was significantly higher in CP than in SKP [factor 1 (photoperiod) $F_{3,322} = 17.74$, $P = 0.0009$, factor 2 (time) $F_{23,322} = 12.48$, $P < 0.0001$, factor 1 x 2 (interaction) $F_{23,322} = 7.748$, $P < 0.0001$, two - way ANOVA, fig 3b]. When compared to short days, the total counts rose in CP but not in SKP ($P = 0.0011$, paired t - test; figure 3c). Furthermore, the total counts varied across the groups, with CP having a higher value than SKP ($P = 0.0009$, unpaired t - test; figure 3c).

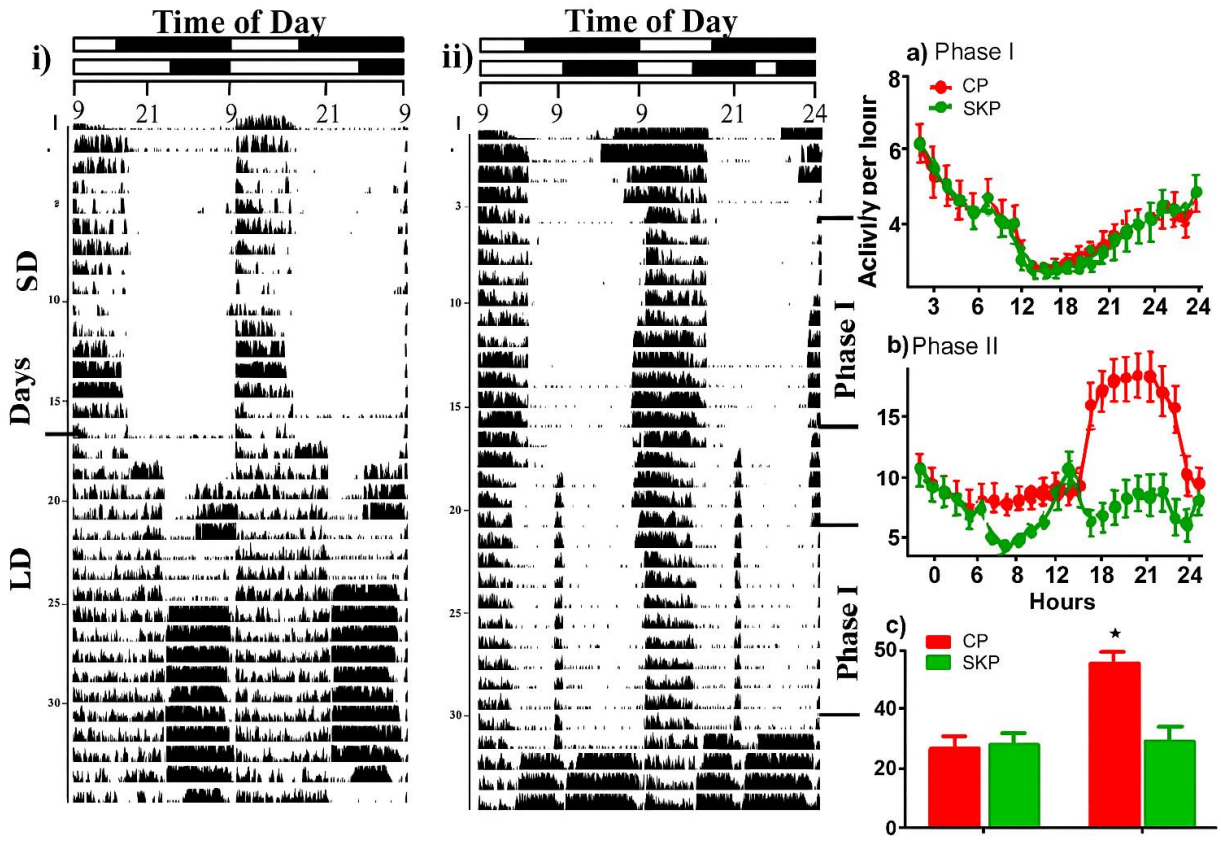


**Figure 1: Actograms of redheaded buntings (n = 12/group) under complete (CP) and skeleton (SKP) photoperiods following SD acclimation. Right panels: mean ± SEM hourly activity (a–b) and daily totals (c) for Phase I (SD) and Phase II (LD). *P < 0.05 indicates significance between CP and SKP.**

**Body mass, body fattening and testis growth**

During the short days, there was no discernible change in the quantity of body fat, body mass, or testis size.

When the birds were subjected to both CP and SKP, they exhibited a significant increase in body mass and testis size. The body mass (CP: $P = 0.0010$, SKP: $P = 0.0002$), fat score (CP: $P < 0.0001$, SKP: $P < 0.0001$), and testis volume (CP: $P < 0.0001$, SKP: $P = 0.0004$, paired t-test, figs 13a - c) were all observed.

However, the magnitude of response was significantly greater under CP (CP vs SKP: body mass: P = 0.0443, fat score: P = 0.0029, testis volume: P = 0.9304, unpaired t-test, figs 13a - c).

**Food intake and utilization efficiency**

When the birds were moved to CP, there was an increase in the amount of food that they consumed; however, there was no such increase detected when they were placed in SKP (CP: P = 0.0185, SKP: P = 0.1367, paired t - test, CP versus SKP: P = 0.1705, unpaired t - test, figure 13d). A substantial improvement in utilisation efficiency was seen in both CP and SKP, with CP exhibiting a greater level of efficiency than SKP (CP: P = 0.0025, SKP: P < 0.0001, paired t - test, CP vs SKP: P = 0.0046, unpaired t - test).

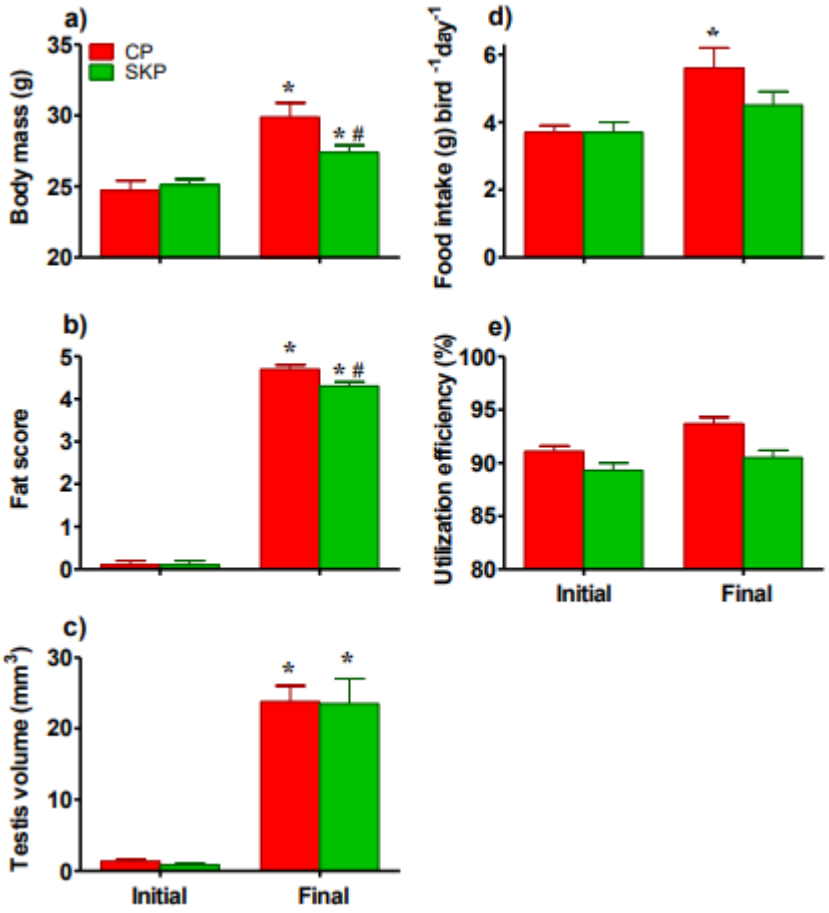


**Figure 2: Mean ± SEM changes in body mass, fat score, testis volume, food intake, and utilization efficiency in redheaded buntings under CP and SKP on day 0 and day 21. *P < 0.05 indicates within-group change; #P < 0.05 indicates between-group difference at day 21.**

**Physiological responses**

**Change in serum metabolites:**

The levels of blood triglycerides and cholesterol did not alter in response to either the full or the skeletal photoperiods. On the other hand, the levels of serum glucose were dramatically lowered in both the CP

and the SKP. Furthermore, when comparing the blood glucose levels under two different photoperiodic treatments, it was found that the levels were considerably lower in the CP group compared to the SKP group ($F_{2,12} = 30.31$, $P < 0.0001$, one-way ANOVA).

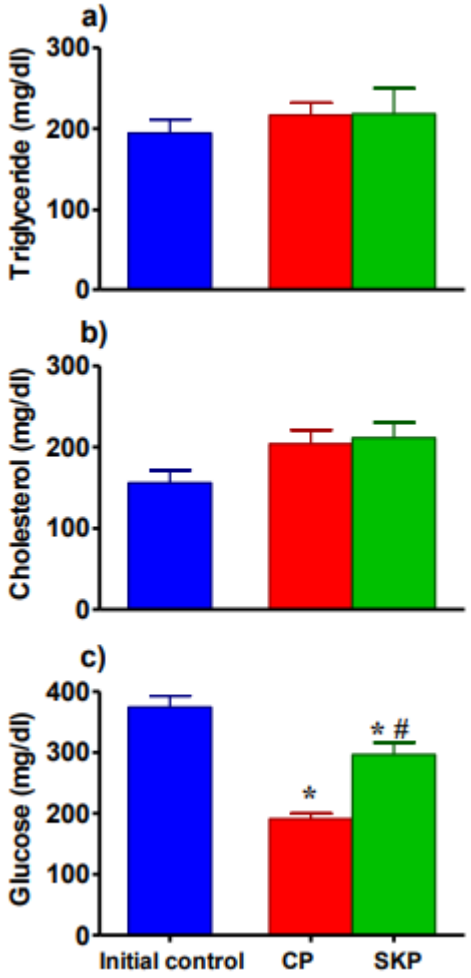


**Figure 3: Mean ± SEM serum triglyceride, cholesterol, and glucose levels in redheaded buntings (n = 4) under CP and SKP on day 0 and day 21. *P < 0.05 vs. initial; #P < 0.05 between groups (one-way ANOVA).**

**Quantitative real - time PCR (qPCR):**

Over the course of two photoperiods, there was a noteworthy difference in the expression of FABP and Bmal1 in the flying muscles and liver. In flight muscles, the relative mRNA expressions of FABP and Bmal1 were found to be upregulated under CP, whereas in liver, they were found to be downregulated under SKP (flight muscles: FABP: $F_{2, 9} = 7.745$, $P = 0.0111$; Bmal1: $F_{2,9} = 4.618$, $P = 0.0417$; liver: FABP: $F_{2,9} = 8.010$, $P = 0.0100$, Bmal1: $F_{2,9} = 5.829$, $P = 0.0238$; one-way ANOVA, figs 15 a, c and f, h). However, there was no difference in the expression of FAT in either of the tissues under CP or SKP (figs 15b, g). In addition, the levels of myoglobin transcripts in flying muscles rose when the subject was exposed to CP ($F_{2,9} = 5.258$, $P = 0.0307$, one-way ANOVA), although creatine kinase did not exhibit any noticeable change. It was noted that there was no change in NPY in the liver during either of the photoperiods.

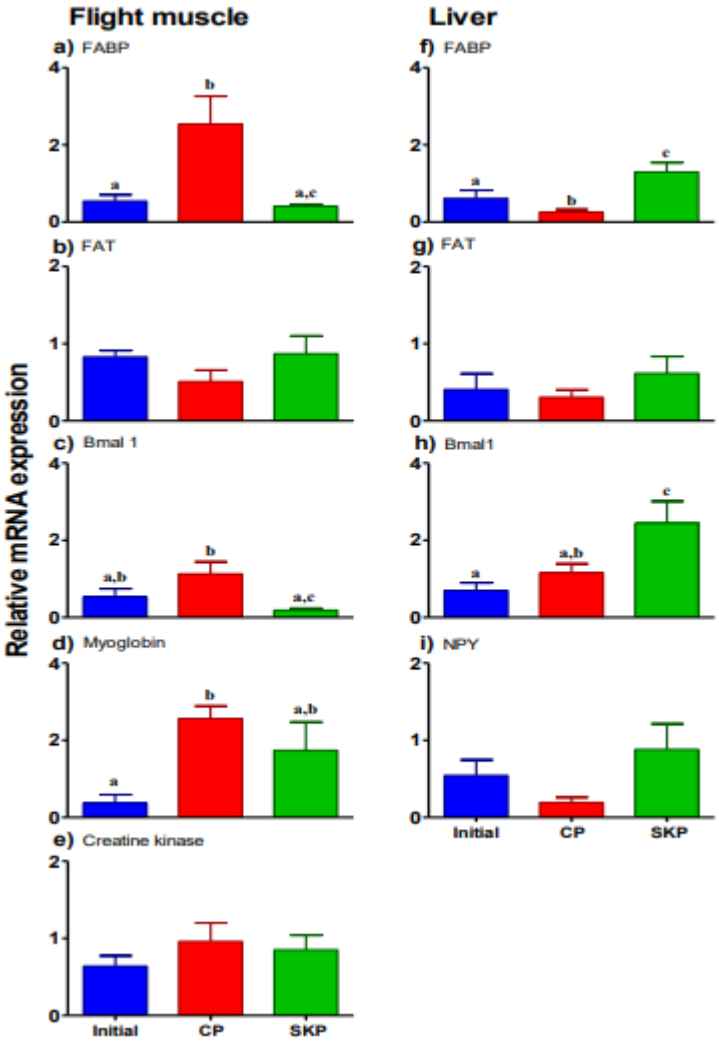


**Figure 4: Mean ± SEM expression of metabolic genes (FABP, FAT, Bmal1, Myoglobin, CK, NPY) in flight muscle (left) and liver (right) of redheaded buntings (n = 4) on day 0 (SD) and after 3 weeks under CP and SKP. Bars with different letters differ significantly (P < 0.0001, one-way ANOVA).**

## CONCLUSION

Migratory birds' timing is being altered as a result of climate change, which poses significant ecological issues in the long run. Disrupting food webs, decreasing the number of successful reproductions, and destabilizing ecological processes like as seed dissemination and pollination are all consequences of earlier arrivals, delayed departures, and mismatched mating cycles. These cascading implications emphasize the immediate need for conservation measures that are integrated and adaptable to climate change. They include the preservation of habitats, predictive ecological modeling, and worldwide monitoring. By gaining an understanding of these temporal alterations and addressing them, policymakers and conservationists may assist in protecting both migratory bird populations and the ecosystems that rely on their ecological functions.

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