# Is There a Shift in the Timing of Western Sandpiper's Migration and Are Local Climate Conditions the Indicators?

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## Abstract

Owing to the evident global warming, species are experiencing rapid declines in their abundances and shifts in geographical ranges. Besides, a change in local climatic conditions such as temperature and precipitation may predict a shift in birds' migration dates. Research on the effects of climate change on short-distance migratory birds have been conducted and well examined, but there has been a lack of study on whether the Western Sandpiper, a long-distance migratory species which passes through coastal British Columbia as a stopover site, alters its migration timing in accordance with changes in the local climatic conditions. We utilized Western Sandpiper observation data from the Department of Environment and Climate Change, Government of Canada, and historical climatic data from the Department of Environment and Natural Resources, Government of Canada. We analyzed the Western Sandpiper (*Calidris mauri)* peak passages and migration timing at their stopover site, the Roberts Bank, British Columbia from 1991 to 2015. By comparing the peak passage of Western Sandpiper during their migration period through the years, we detected a significant advance in the Western Sandpiper's migration dates. Linear regressions enabled us to enquire the relationship between mean, maximum and minimum temperature and precipitation indices at Western Sandpiper's stopover site. The weak correlation between the alteration in the timing of Western Sandpiper's migration and local climate change suggests that global climate change did not impact on this species. Adaptation, alteration of distribution patterns, or adjustment of migration timing is therefore consequential for the bird species in order to persist.

## Introduction

There is overwhelming evidence that the contemporary anthropogenic climate change involving global rising temperatures is due to the intensive release of greenhouse gases from industrial activities. The increased concentration of greenhouse gases also accelerates the global mean rates of both evaporation and precipitation simultaneously (Manabe, 2019). In addition, the unusual distribution of rainfall events worldwide has widely caused dry areas drier and wet places wetter

(Trenberth, 2011). Presumably, a shift in environmental indices such as temperature and precipitation is predicted to influence species abundance and distribution in the local community. Species fail to adapt to the new environment face great probabilities of population declines and extinctions (Porfirio et al., 2016). Fortunately, evolution enables species to alter their behavior, morphology and/or physiology as responses to environmental changes (Parmesan et al., 1999, Ficetola et al., 2016). For example, many species of butterfly exhibited northwards range shifts alongside the warming of regional temperatures (Parmesan et al., 1999). Furthermore, there are widespread cases where insects shift their springtime phenology earlier as the local temperatures rise (Forrest, 2016).

Phenology refers to the timing of biological events that are associated with the seasons (Forrest, 2016). Especially for migratory birds who respond to seasonality in abiotic patterns by repeated evolution, the temporal schedule of migration often represents an ideal match with the local environmental conditions (Knudsen, 2011). Therefore, changes in species phenology are often regarded as one of the most conspicuous signs of global climate change. A previous research on short-distance migratory birds have revealed advancements in their arrival dates in accordance with climate change. The study indicated that these migrants were able to utilize meteorological clues that may predict the weather at the destination and minimum temperatures determined their arrival date during winter migration (Zaifman et al., 2017).

In our study, the target organism is the Western Sandpiper. It is an abundant shorebird that gathers in large flocks that normally ranges from hundreds to thousands in California and Alaska. It is also a long distance migrant that migrates between western Alaska and Peru during their spring migration. During their flyway, they stop over at the Roberts Bank, British Columbia to refuel (Franks et al., 2014). By analyzing the pattern of Western Sandpiper's migration timing at the stopover site as well as its relationship between the local climatic variables prior to migration, we fill in gaps in the potential alteration in a long-distance migrant's spring migration timing, and whether it is associated with the destination's climatic cues. Thus, this study can provide insights for understanding the threats underlined in the current anthropogenic environmental crisis and may provide influential future conservation efforts on Western Sandpipers and their phylogenetic families.

Our hypothesis is that there is a shift in the Western Sandpiper's migration timing over the 25 years, and the alteration is caused by changes in local climatic variables prior to migration. We predict an advancement in the Western Sandpiper's migration timing over the study period. Besides, the advancement is positively associated with the study site's increasing temperature and precipitation a week prior to migration.

## Methods

### *Data Description*

The Western Sandpiper abundance data was obtained from the Roberts Bank Shorebird Survey conducted in BC by Environment and Climate Change, Government of Canada. The researchers surveyed species-specific abundance counts including Western Sandpiper (Calidris mauri) during its migration period (April-May) from 1991 to 2015 at Roberts Bank's mudflat based on observation . The daily counts started from April 15 each year till bird abundance <1000 or May 15, whichever came first at The Brunswick Point study site (49°03′ N, 123°09′ W).

We also selected datasets for climatic conditions in Delta Tsawwassen Beach, BC (latitude: 49°00'39.400'' N longitude:123°05'36.000'' W) for years from 1991-2015. These historical climate datasets were obtained from the Daily Data Report produced by the Department of Environment and Natural Resources, Government of Canada. Specialized scientists recorded the hourly climatological data at observing stations, using instruments such as satellites and weather balloons et cetera. The Delta Tsawwassen Beach was the closest site to the given coordinates where the actual bird abundance survey was conducted, and this site contained sufficient climate data (i.e. having data for the studied time intervals).

### *Data Analysis*

All the data analysis and plotting were performed in R (version 3.6.1). Rows containing NAs in the Western Sandpiper observation counts, temperature and precipitation were removed before statistical analyses.

*Question 1: Did the Western Sandpiper's migration timing change from 1991 to 2015?*

We selected two columns from the Shorebird Survey: 'date' and 'Western Sandpiper counts'. To use 'date' as a numeric variable, we converted each calendar date into a julian date. A weighted mean migration date was calculated for each year to represent the time at which most of the birds have arrived. The mean for each year was calculated by the formula:

*∑ (Julian date * (bird counts on the given date/total counts in the given year)).*

Each date contributed differently to the final average and the contribution was determined by the bird abundance on that date. Normality test's result showed that the weighted means were normally distributed. A linear regression test was performed between weighted means and years. A scatter plot with a line of best fit was used to visualize the relationship.

*Question 2: Was the shift in the Western Sandpiper's migration timing associated with the stopover site's local mean/maximum/minimum temperature or precipitation from 1991 to 2015?*

We combined 25 climate datasets by rows and selected 4 variables: daily mean, maximum and minimum temperature and precipitation. We rounded the weighted mean migration date to the nearest integer and selected the climatic data one week prior to the rounded value for each year. Even though the plotted histogram showed that each 'temperature' variable was normally distributed, the distribution of 'precipitation' was largely right skewed - more than ¾ of the data was equal to 0. Therefore, we used the precipitation as a binary variable - whether there was rainfall, and converted all non-zero values to 1. We calculate the average of mean, maximum and minimum temperature and the total counts of rainy days for each year. The distributions of these variables were normal. The saturated linear regression model was built as:

Weighted mean migration date ~ max/min/mean temperature * precipitation.

The best model was selected based on the lowest AICc test value. The best model was visualized by a scatter plot with the trend line.

*Question 3: Did the local mean/maximum/minimum temperature and precipitation change from 1991 to 2015?*

We used the one-week time period prior to the (rounded) weighted mean migration date in 1991 as a reference and compared the climatic data (mean/maximum/minimum temperature and precipitation) during the same period for the 25 years. Similar to what we have done before in question 2, we calculated the averages of the temperature variables and the total counts of rainy days for each year. After checking the normality, four linear regression tests were performed between each climatic variable versus 'year'. One scatter plot with all four variables against 'year' was plotted.

In addition, we used a similar method to compare climatic variables for the one-week time period prior to the yearly (weighted mean) migration date. In this case, the time periods would be different if the (weighted mean) migration date differed each year.

## Results

*Question 1:*

The Western Sandpiper's migration date significantly shift earlier from 1991 to 2015 (Figure 1). The advancement was 0.19 day per year ($F_{1,21}$=13.68, $p$=0.00133).

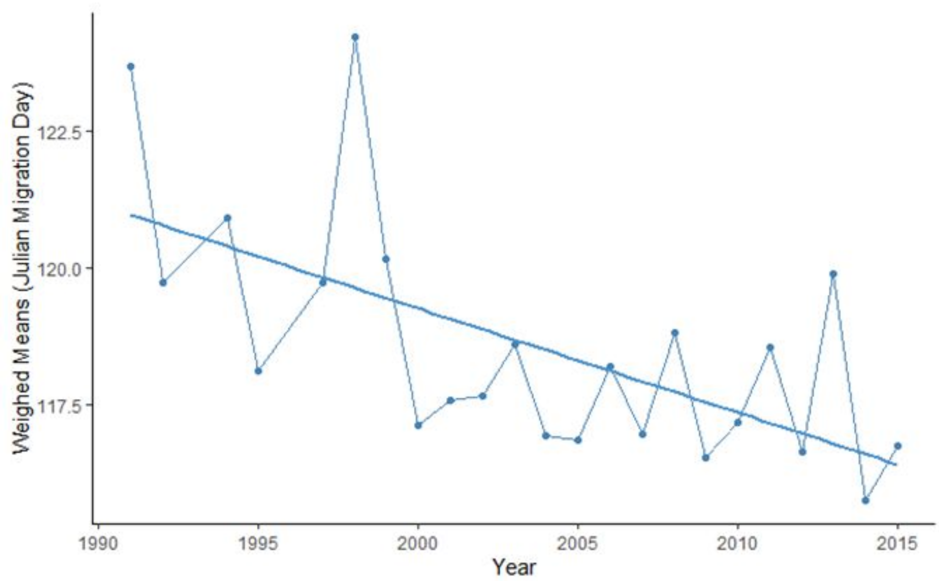

Figure 1. Weighted mean of Julian migration date showed a decreasing trend over 25 years (Linear regression: $F_{1,21}$=13.68, $p$=0.00133).

*Question 2:*

AICc results showed that the model with the daily mean temperature as a single predictor was the best model (Table 1). This model showed a significant positive relationship between migration dates and daily mean temperatures (Figure 2). For every unit of decrease in temperature, the migration date advanced 0.73 day (Linear regression: $F_{1,20}$=4.831, $p$=0.0399). This suggested that the earlier shift in Figure 1 was associated with decreasing temperatures.

Table 1. AICc scores for 10 linear models with temperature and precipitation as main effects and their interactions.

| | df <dbl> | AICc <dbl> |
|---|---|---|
| mean_precip_int | 5 | 104.89581 |
| mean_precip | 4 | 101.59840 |
| mean_only | 3 | 98.61810 |
| precip_only | 3 | 102.64631 |
| max_precip_int | 5 | 105.72378 |
| max_precip | 4 | 102.32805 |
| max_only | 3 | 99.31103 |
| min_precip_int | 5 | 105.79888 |
| min_precip | 4 | 102.43352 |
| min_only | 3 | 99.79776 |

1-10 of 10 rows

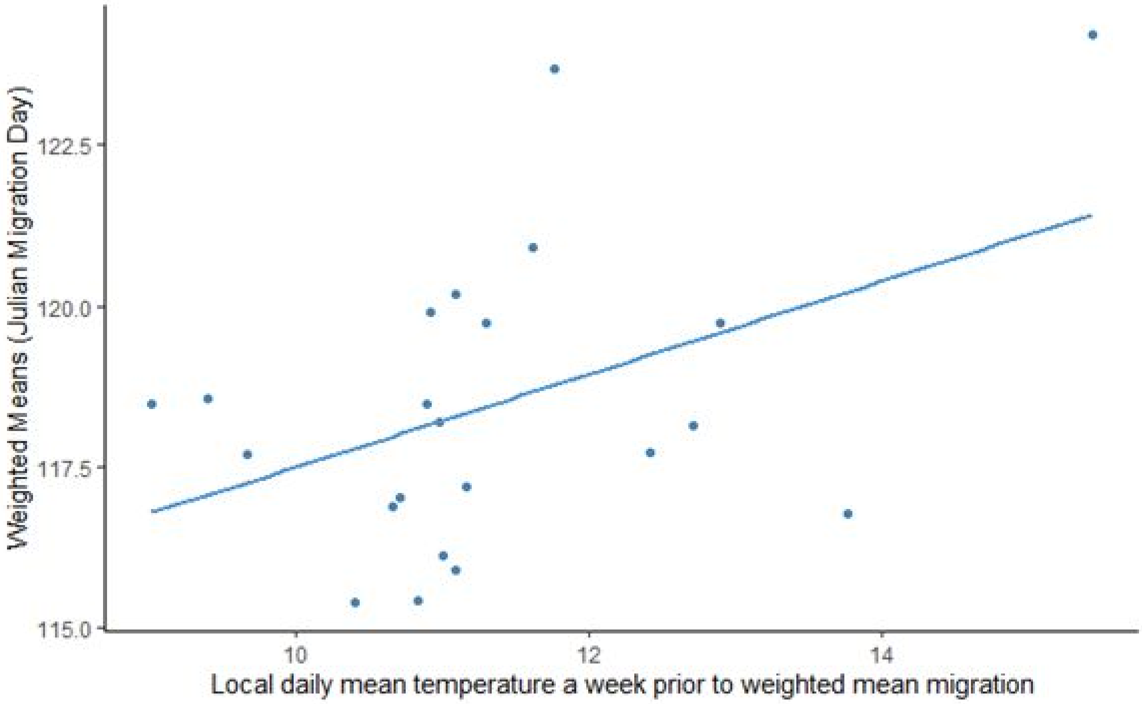


Figure 2. Positive relationship between weighted mean julian migration day and daily mean temperature one week prior to the weighted mean migration (Linear regression: $F_{1,20}$=4.831, $p$=0.0399).

<u>*Question 3:*</u>

In 1991, the rounded weighted mean migration date was 124, therefore the one week period we used as reference for each year was Julian days 117-124. Linear tests between climatic variables vs. year showed no significant results (Table 2a), which indicated the temperature and precipitation were stable during that period over the 25 years (Figure 3a).

Alternatively, the climatic variables one week prior to the migration date which varied across years showed significant results. The minimum and mean temperature significantly decreased over the 25 years, while the maximum temperature and precipitation remained stable (Table 2b; Figure 3b). The decrease in temperature was consistent with the result  in Figure 2. Decreasing temperature was causally linked to advancement in Western Sandpiper's migration date.

Table 2a. Results from linear regression models testing climatic variables vs. year. Climatic data was from the same time period (julian days 117-124) from 1991-2015. Year 2004 was excluded due to missing climatic data.

| **Linear Model** | ***df*** | **Estimate** | ***F* Statistic** | ***p*-value** |
|---|---|---|---|---|
| Meantemp ~ Year | 23 | -0.01131 | 0.05878 | 0.811 |
| Mintemp ~ Year | 23 | -0.05414 | 1.623 | 0.215 |
| Maxtemp ~ Year | 23 | 0.03380 | 0.4083 | 0.529 |
| Precipitation ~ Year | 23 | 0.02308 | 0.1744 | 0.680 |

Table 2b. Results from linear regression models testing climatic variables vs. year. Climatic data was selected one week prior to the yearly (weighted mean) migration date. Year 1993 and 2004 was excluded due to missing bird abundance data. Year 1996 was excluded due to missing climatic data.

| **Linear Model** | ***df*** | **Estimate** | ***F* Statistic** | ***p*-value** |
|---|---|---|---|---|
| Meantemp ~ Year | 20 | -0.09267 | 5.874 | 0.0250* |
| Mintemp ~ Year | 20 | -0.11830 | 13.35 | 0.00158** |
| Maxtemp ~ Year | 20 | -0.06469 | 1.662 | 0.212 |
| Precipitation ~ Year | 20 | 0.05175 | 0.6239 | 0.439 |

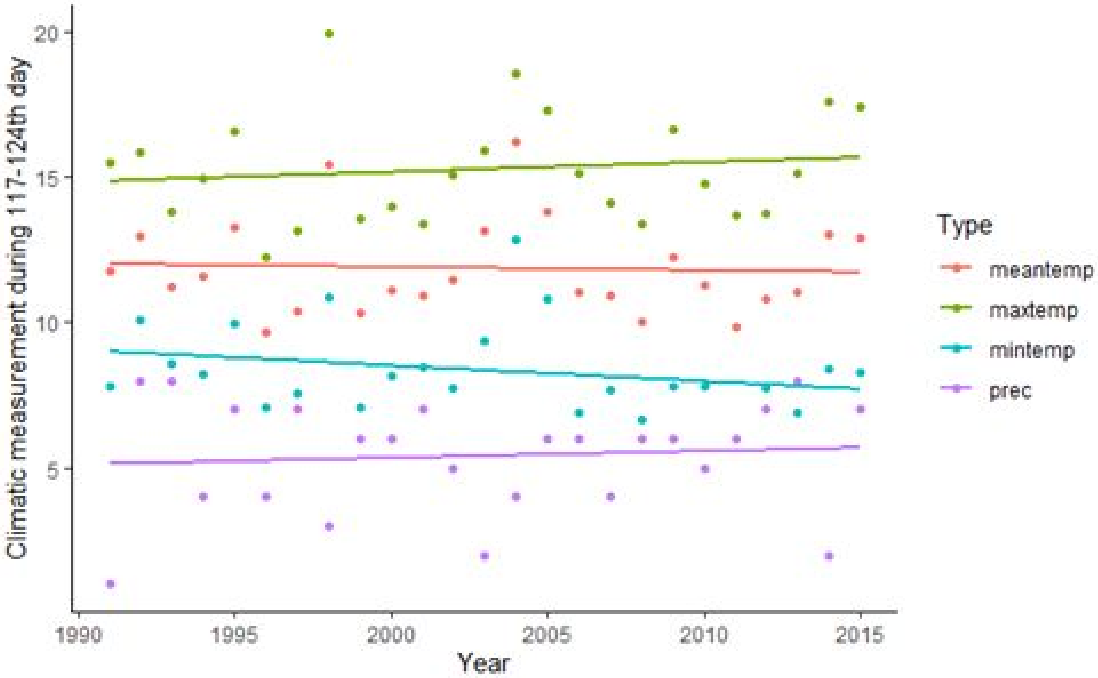


Figure 3a. Comparison of climatic measurements during the same time period (117-124th day) among 25 years. Linear tests showed no significant change.

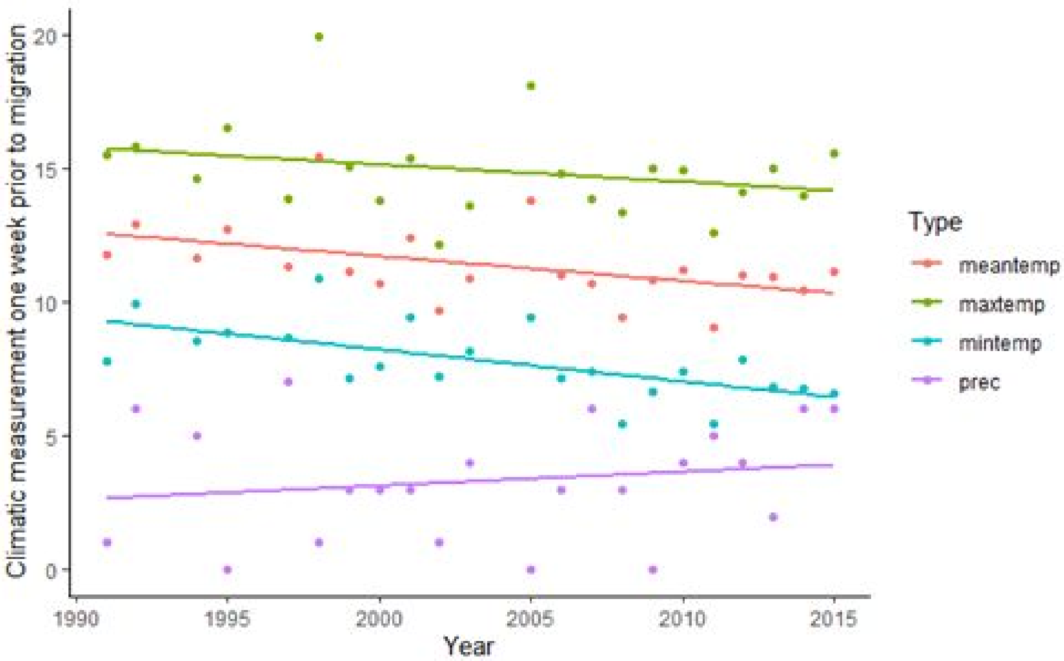


Figure 4. Climatic measurements one week prior to the yearly weighted mean migration date. Linear tests showed significant decreases in minimum temperature and mean temperature. ($F_{1,20}$=13.35, $p$=0.00158; $F_{1,20}$=5.874, $p$=0.0250).

## Discussion

The timing of the Western Sandpiper's migration did alter from 1991 to 2015. It shifted approximately 0.19 day earlier per year. However, this advancement was not due to the local temperature fluctuations or changes in the precipitation frequencies during the study period. Therefore, our hypothesis raised for this study only partially being proved since the climate condition in the observation area stayed quite constant over time.

Even though local climatic conditions did not impact the Western Sandpiper's migration, there are other possibilities that might have resulted in the shift. For example, the Western Sandpiper shifted their migration timing earlier because they intentionally seeked for a cooler climate. Benefits that a cooler climate can bring about to a shorebird species such as the Western Sandpiper include more foraging opportunities. During their spring migration, the Western Sandpipers generally feed on aquatic invertebrates such as crustaceans and mollusks at the rich shallow water areas at river deltas as their primary energy source (Franks et al., 2014). Parmesan and his colleagues (1999) showed that temperature is one of the most deterministic factors influencing the mortality and growth rates of juvenile and adult aquatic invertebrates' life stages. Therefore, an earlier arrival may offer a higher foraging success to those Western Sandpipers, allowing them to fuel themselves for the following journey. Thinking about the trophic level, the competitor's from both inter-communities and intra-communities need to be taken into account as well. However, few studies have addressed changes in bird community composition with respect to climate change (Endre, 2011) and migration routes.

There are many limitations in our study. For example, we only have the Western Sandpiper's observation data at their stopover site. While studying a long-distance migratory species, it might be best to survey and analyze species abundance along their entire flyway, and this includes all of their starting point, stopovers, and the destination. Besides, we do not yet have a detailed data of environmental factors in both their departure spot and destination.

Moreover, the study site we pick in BC is only a stopover site for Western Sandpipers, we did not dig deep on the climate and other biotic condition of their migration starting point and destination. Considering the constant temperature condition on the observation site, we predict that there might be something at their starting point informs birds an early departure or something at the destination encourages them or forces them to arrive earlier so that they also pass by the stopover site earlier. One guess is to compete for limited breeding resource or nesting spot. Thus, more attention is needed for other biotic and abiotic factors that will affect the Western Sandpipers migration routine.

## Conclusion

Our study investigated in the migration period of Western Sandpiper. Based on our species data from the Roberts Bank Shorebird Survey and local climate data, we wanted to examine whether the migration timing of Western Sandpipers changed over 25 years from 1991 to 2015, and whether this change related to local climate conditions. We predicted that there might be a local climate change in BC since climate change is a global event and Western Sandpipers' migration timing also changed as a response to acclimate the changing climate. We found that our species arrived BC in advance and also, the positive correlation between the timing of migration and temperature. Nonetheless, local weather conditions did not change too much through the 25-year period. In light of this result, we made further conjectures and suggests that future studies should include bird abundance data, prey abundance data and abiotic environmental data at all the starting, stopover and destinations to figure out what exactly is causing this earlier shift for Western Sandpipers migration timing.

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