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

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Abstract

Changes in climatic conditions such as temperature and precipitation may result in shifts in birds' migration dates. The effects of climate change on short-distance migratory birds have been well examined, but there lacked studies on long-distance migratory species, such as Western Sandpiper (*Calidris mauri)*. We utilized Western Sandpiper observation data at their stopover site, the Roberts Bank, British Columbia, and the local historical climatic data, from the Government of Canada. We hypothesized that the Western Sandpiper's migration timing altered from 1991 to 2015 due to changes in the local temperature and precipitation patterns. Our results revealed a significant advancement in migration timing and the mean and minimum temperature one week prior to when most of the birds arrived significantly decreased. However, by using the same one week in 1991 as a reference, the local climate during this time period stayed constant for 25 years. Therefore, rather than responding to climate changes, Western Sandpipers might intentionally seek cooler weather.

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 butterflies 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. Previous research on short-distance migratory birds has revealed advancements in their arrival dates following the local 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 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 stopover 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.

We hypothesize 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 were 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 prior to 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. The normality test 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 linear 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 columns: 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 and 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.

Also, 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

<u>*Question 1:*</u>

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).

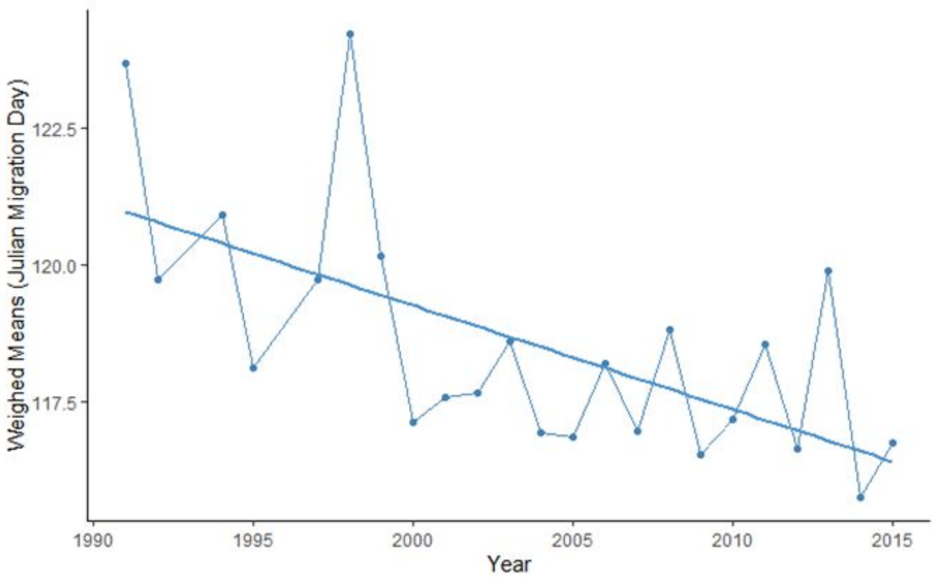

Figure 1. The weighted mean of Julian migration date showed a decreasing trend over 25 years (Linear regression: $F_{1,21}$=13.68, p=0.00133).

<u>*Question 2:*</u>

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 days (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

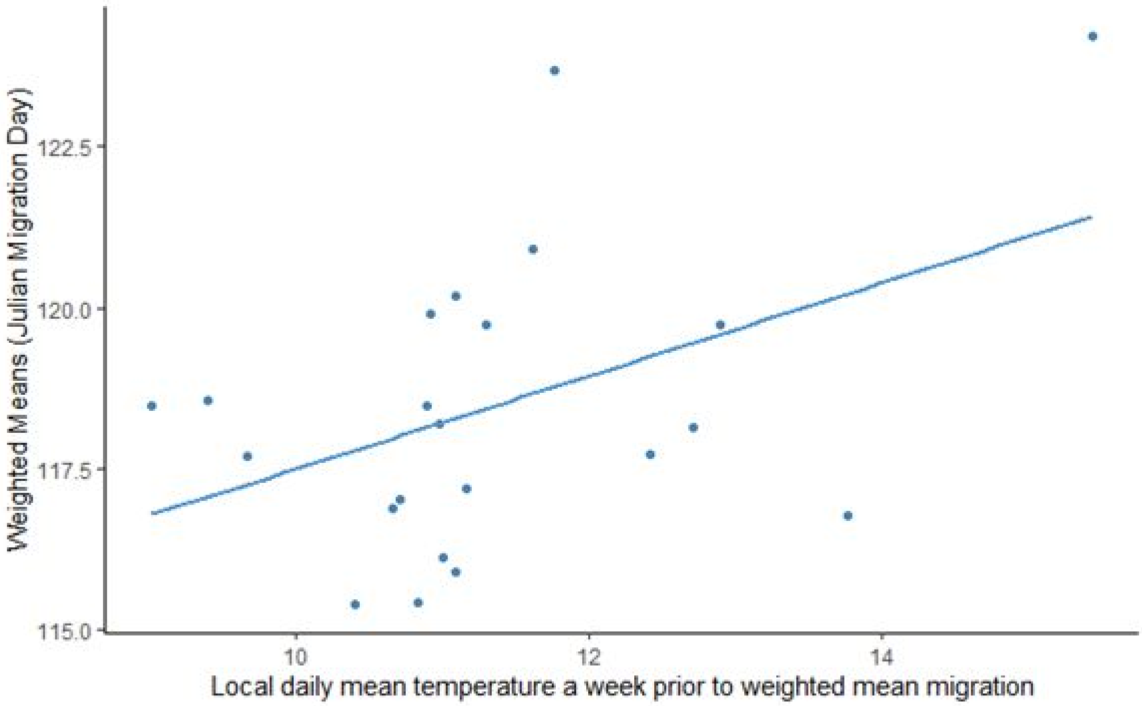

Figure 2. A positive relationship between weighted mean migration day and daily mean temperature one week prior to the weighted mean migration (Linear regression: $F_{1,20}$=4.831, p=0.0399).

Question 3:

In 1991, the rounded weighted mean migration date was 124, therefore the one week period we used as a 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. The 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. The year 1993 and 1996 were excluded due to missing bird abundance data. The year 2004 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

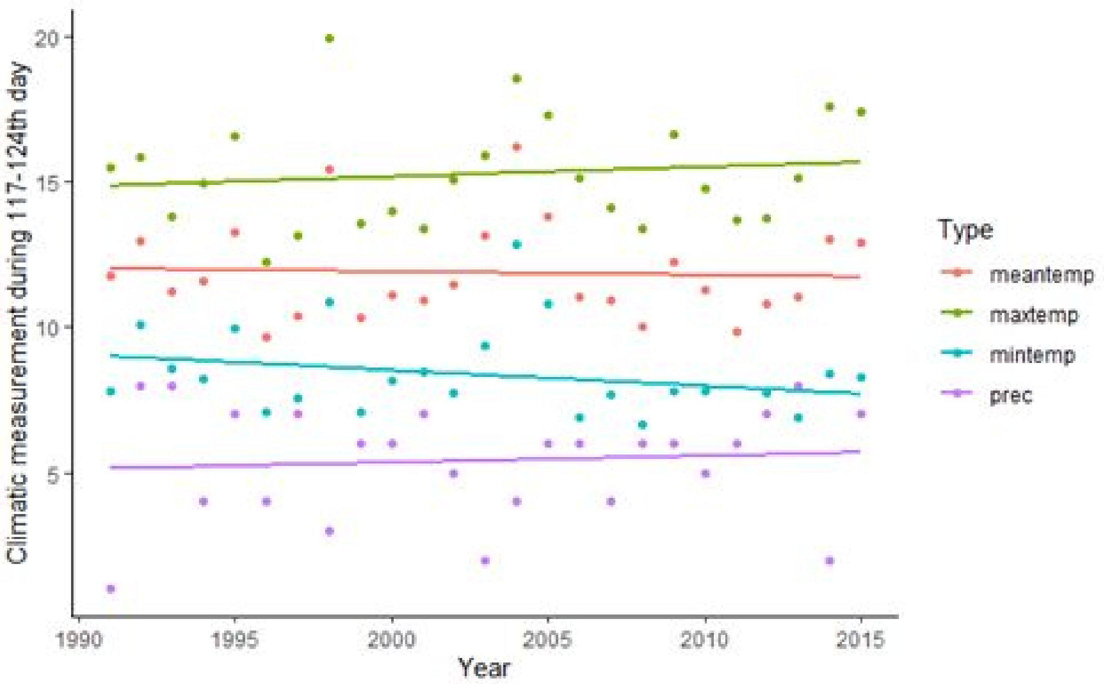

Figure 3a. Comparison of climatic measurements during the same time period (117-124th day) among 25 years. Linear tests showed no significant change.

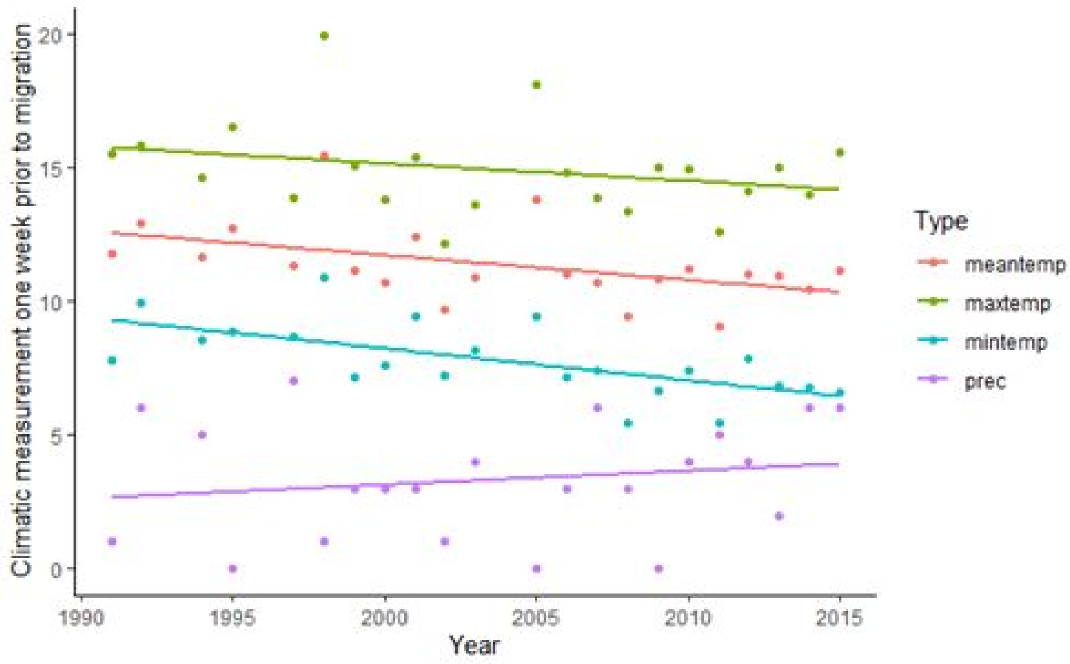

Figure 4. Climatic measurements one week prior to the yearly weighted mean migration date. Linear tests showed significant decreases in minimum temperature and mean temperature. ($F_{1,20}$=13.35, p=0.00158; $F_{1,20}$=5.874, p=0.0250).

Discussion

A phenological alteration can be an evolutionary adaptation for species to respond to environmental changes. Our results supported the hypothesis that the timing of the Western Sandpiper's migration altered from 1991 to 2015. However, since our results showed the climatic conditions at BC remained stable for 25 years, the advancement was not due to the local temperature fluctuations or changes in the precipitation frequencies during the study period.

One possible reason for the earlier shift in the Western Sandpiper's migration timing was that rather than responding to changes, Western Sandpipers intentionally sought for a cooler climate. Our results showed that the daily mean and minimum temperature when most of the birds have arrived indeed decreased over the 25 years. 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. In addition, avoiding interspecific competition with Dunlin (*Calidris alpina*), another migratory shorebird species within the same community, on the foraging/breeding ground might be another reason why the Western Sandpipers alter their migration timing.

There are limitations in our study. For example, we only have the Western Sandpiper's observation data at their stopover site, British Columbia. While studying a long-distance migratory species, it might be best to survey and analyze their abundance along the entire flyway, and this includes all of their starting point, stopovers, and the destination. Besides, we do not yet have detailed data of prey abundance and environmental factors at both their departure spot and destination. Changes in these factors at their starting point can inform the birds to depart earlier as well; similarly, changes at the destination can also encourage them or forces them to arrive earlier, as a result, they pass by the stopover site earlier. Future research should pay attention to both biotic and abiotic factors that will affect 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 examined 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 Western Sandpipers' migration timing changed as a response to the local climate change in BC. Nonetheless, based on the results, local weather conditions did not change too much through the 25 years. However, the birds' migration timing indeed advanced. 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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