Changes In Spring Arrival Dates of Rufous Hummingbirds (*Selasphorus rufus*) In Western North America In the Past Century

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CHANGES IN SPRING ARRIVAL DATES OF RUFOUS HUMMINGBIRDS (*SELASPHORUS RUFUS*) IN WESTERN NORTH AMERICA IN THE PAST CENTURY

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ABSTRACT.—Warming temperatures have been linked to advancing spring migration dates of birds, although most studies have been conducted at individual sites. Problems may arise ecologically if birds arrive or depart before or after associated food resources such as plants or insects reach critical lifecycle stages. Here, I compare mean first arrival dates of the Rufous Hummingbird (*Selasphorus rufus*), a prolific pollinator and long-distance migrant with the northernmost breeding range of any North American hummingbird, between 1895–1969 and 2006–2015 at eight observation locations in Oregon, Washington, and British Columbia. Historical arrivals were reported through the North American Bird Phenology Program, and recent arrivals were estimated from temporal occupancy patterns using eBird checklists. Results indicated that hummingbirds arrived 8 and 11 days later in the recent time period in two coastal cities in Oregon and 7–17 days earlier in northern, more inland cities in Washington and British Columbia. Fewer days were noted between arrivals in more northerly areas in the recent time period suggesting that birds may now be migrating faster than in the previous time period. Spring temperatures have increased in the past century in much of this region, and birds arrived earlier in years with warmer spring temperatures to suggest that migratory advances are climate-related. Later mean first arrivals reported in coastal regions of Oregon in the recent time period may suggest that Rufous Hummingbirds are bypassing coastal areas to take advantage of more predictable conditions along inland migratory routes or are shifting their breeding ranges northward, notions both supported by declining population trends observed in Breeding Bird Survey data. My results demonstrate a climate-related advancement of Rufous Hummingbirds in western North America and provide justification for the investigation of the ecological impacts of climate change on birds in coastal vs. inland environments. In addition, I provide a framework for comparing information from two extensive and emerging datasets to better understand the impacts of climate change on birds at broad spatial and temporal scales. *Received 12 August 2016. Accepted 19 December 2016.*

Key words: bird migration, citizen science, climate change, eBird, North American Bird Phenology Program, phenology, *Selasphorus rufus*.

Birds are charismatic and relatively easy to identify, and monitoring programs have been in place for more than a century (Wilson 2007, Knudsen et al. 2011, Zelt 2015). At the same time, the average temperature of the earth has warmed by ~0.74 °C, with the rate of warming over the last 50 years nearly double that of the past 100 years (Intergovernmental Panel on Climate Change 2007). Recent studies indicate that spring arrival dates of many migratory bird species are advancing in response to climate change (Marra et al. 2005, Miller-Rushing et al. 2008, Travers et al. 2015, Newson et al. 2016). Ecologically, potential problems may result when birds respond to cues to initiate migration from their wintering grounds that are different than the cues that initiate metabolic activity in insects and plants (i.e., species that serve as birds' primary food resources) in more temperate breeding areas (McKinney et al. 2012). This potential asynchrony can negatively impact bird populations (Møller et al. 2008, Stephens et al. 2016) and the pollination and biological pest suppression services that birds provide (Sekercioglu et al. 2004).

Migratory data for a variety of North American bird species are becoming available at unprecedented spatial scales with the emergence of the Citizen Science program eBird (www.ebird.org). By mid-year 2013, eBird had received >140 million observations from 150,000 observers (Sullivan et al. 2014). Data are submitted in checklist form and made publicly available through a variety of outlets including the Avian Knowledge Network (avianknowledge.net) and DataONE (dataone.org). This information has furthered our understanding of avian ranges, abundances, and migration patterns (Wood et al. 2011, Hurlbert and Liang 2012, Sullivan et al. 2014). Users of eBird are able to submit historical checklists from any time period; however, data coverage is limited prior to 2002 when eBird was initiated (Sullivan et al. 2014). This makes it difficult to use eBird data to assess the impacts of long-term environmental changes.

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A powerful, but lesser-known counterpart to eBird is the North American Bird Phenology Program (hereafter, 'NABPP'; www.pwrc.usgs.gov/bpp/). It operated from 1881 to 1970 and coordinated the efforts of hundreds of naturalists to understand bird migration and distribution patterns for >800 bird species throughout North America (Zelt et al. 2012). Data from this survey guided the development of early avian field guides and helped establish early iterations of the American Ornithologists' Union's Checklist of North American Birds (Allen 1910). Through the recent efforts of the United States Geological Survey, nearly six million first arrival and observation records have been digitized and are being transcribed to make this unique historical dataset available to scientists (Zelt 2015). With historical climate data also readily available through the National Climate Data Center (www.ncdc.noaa.gov/cdo-web/search), the potential is enormous to compile these resources to assess the impacts of climate change on bird migration at broad spatial and temporal scales.

Hummingbirds are Neotropical migrants that naturalists find particularly charismatic (Healy and Calder 2006). Of the ~15 species of hummingbirds that regularly breed in the United States, 14 are found in western states, including the 'extremist' Rufous Hummingbird (*Selasphorus rufus;* Healy and Calder 2006). Rufous Hummingbirds winter near the equator and migrate >1,500 km northward in March and April along the Pacific Coast of the United States to follow areas of abundant floral resources. They breed from Oregon to Alaska, at higher latitudes than any other hummingbird species (up to 61° N; Healy and Calder 2006, Bonfield 2014). They leave their breeding territories in mid-July (Campbell et al. 2007) and initiate a more westerly southbound migratory journey, where they are often observed feeding on the nectar of late-blooming plants in high alpine meadows of the Rocky Mountains (Healy and Calder 2006, La Sorte et al. 2014).

Much about the migration ecology of Rufous Hummingbirds remains unknown, however, which is surprising given their popularity among birders (Bonfield 2014) and their 2.1% annual population decline that has been noted in data collected by the Breeding Bird Survey between 1966–2013 (Sauer et al. 2014). From an ecological standpoint, Rufous Hummingbirds also provide important pollination services in various life zones throughout their annual lifecycle (e.g., deserts, coastal forests, alpine meadows; Berlanga et al. 2010, Abrahamczyk and Renner 2015, Waser and Price 2016). Moran et al. (2013) used stable isotope analysis to explore migratory connectivity in Rufous Hummingbirds between their wintering and breeding ranges and showed the females breeding in western areas in North America tended to overwinter at higher elevations in Mexico. Supp et al. (2015) used eBird data from 2008–2013 to describe the annual variation in spring migration patterns of five North American hummingbird species and showed that the onset of migration varied less than the timing of arrival to wintering grounds. They also reported that long-distance migrants, such as Rufous Hummingbirds, exhibited less annual variation in the route and timing of migration than did bird species with shorter distance migrations. A broad-scale study that assesses long-term changes in the migration phenology of Rufous Hummingbirds has yet to be conducted, however.

Courter et al. (2013a) showed that arrival dates of a similar long-distance migrant in the eastern United States (i.e., the Ruby-throated Hummingbird; A*rchilochus colubris*) have advanced by ~14 days in the past century in response to changes in temperature, but in general, studies involving migration phenology have been scarcer in the western United States (e.g., Macmynowki et al. 2007, McKinney et al. 2012) than in the east (e.g., Butler 2003, Ledneva et al. 2004, Marra et al. 2005, Miller-Rushing et al. 2008, Van Buskirk et al. 2009), although regional differences have been reported in the effects of climate change (Cayan et al. 2001). Therefore, the objective of this study is to assess migratory changes in Rufous Hummingbirds in western North America from 1895–2015 in relation to climate variables.

METHODS

Historical Observations

Historical migration data for Rufous Hummingbirds (1895–1969; $n = 436$) were provided by the NABPP and transcribed from handwritten arrival cards by J.R.C. and student volunteers. Preliminary analyses indicated that spring first arrival records were most abundant in Oregon and

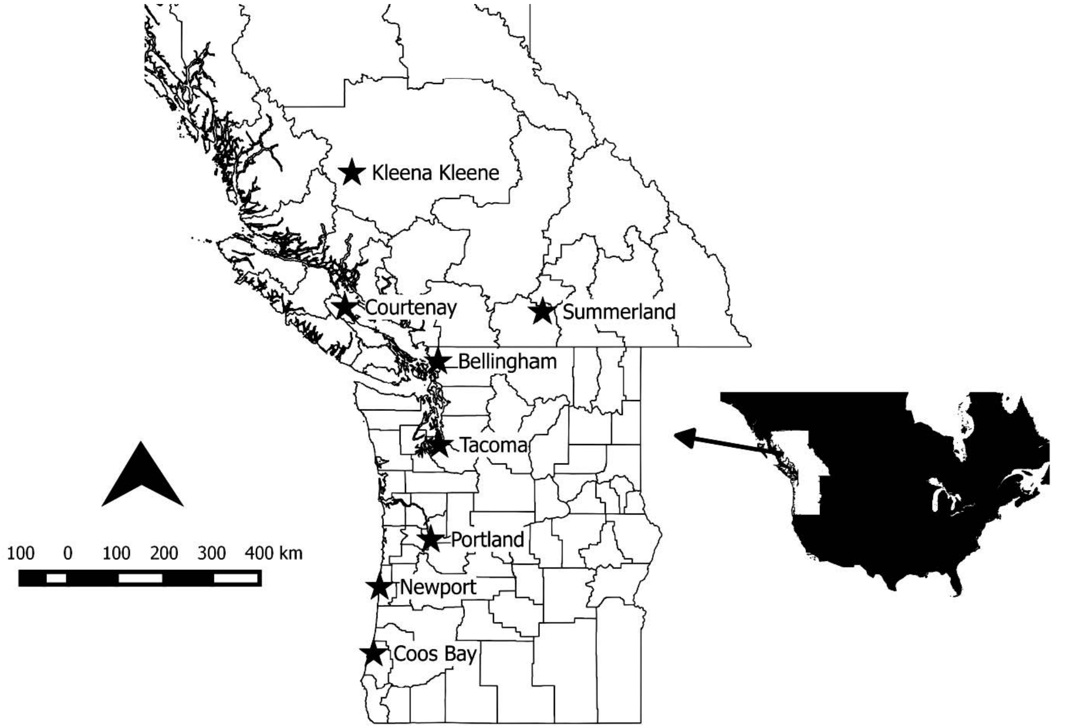

FIG. 1. Locations in Oregon, Washington, U.S., and British Columbia, Canada, where mean first arrival dates of Rufous Hummingbirds were compared between a historical (1895–1969) and a recent (2006–2015) time period.

Washington, U.S., and British Columbia, Canada, and that most records were submitted by a relatively small number of faithful observers who submitted records for a particular location over a period of multiple years. Zelt (2015) showed that 'number of observations submitted' (i.e., degree of participation) by NABPP volunteers was associated with accuracy in data reporting, therefore, I only included observations in my analysis from participants who submitted observations for >5 years at the same or a similar location (i.e., within 40 km). This resulted in eight usable location/observer combinations; three in Oregon, two in Washington, and three in British Columbia (Fig. 1). Locations were geocoded using the Google Maps function in the MMGIS plug-in of QGIS (Quantum GIS Development Team 2015).

Recent Observation

Recent data (2006–2015) for Rufous Hummingbirds from the Citizen Science program eBird were compiled from regions surrounding the eight historical observation locations (available at: www.ebird.org). Participation in eBird has increased since its inception in 2002, and assessing records starting in 2006 ensured that analyses would be based on data from a period of high data availability (Sullivan et al. 2014, Supp et al. 2015). Only vetted and 'complete' checklists (i.e., those that included all birds observed during an observation period) were analyzed. Mean first arrival dates were estimated from eBird checklists based on temporal occupancy patterns according to the methods of Hurlbert and Liang (2012).

All eBird checklists submitted in a five-county region surrounding each historical observation location were included in the analysis to establish a sufficient sample size to assess temporal occupancy patterns. Checklists were grouped into 16 periods at each location, each corresponding to ~1 week from 1 February to 31 May (i.e., the approximate migration period of Rufous Hummingbirds). I calculated a frequency value for each week to indicate the percentage of checklists that included an observation of a Rufous Hummingbird, and I built a model using a four-parameter

TABLE 1. First arrival dates of Rufous Hummingbirds in a historical (1895–1968) and recent (2006–2015) time period at eight locations in North America arranged by latitude. Differences in mean arrivals compared using *t*-tests.

					First arrivals (1895–1968)[a]			First arrivals (2006–2015)[b]				Difference		
City	St./Prov.	Country	Latitude	Longitude	*n*	DOY[c]	SE	*n*	DOY	SE	Days earlier	SE	df	P^d
Coos Bay	OR	USA	43° 22′ N	124° 13′ W	9	59.8	2.67	7	70.9	1.99	−11.1	3.51	14	0.004
Newport	OR	USA	44° 38′ N	124° 03′ W	6	67.3	2.22	7	75.4	1.29	−8.1	2.47	11	0.004
Portland	OR	USA	45° 31′ N	122° 41′ W	8	91.1	5.89	9	84.0	3.00	7.1	6.39	15	0.14
Tacoma	WA	USA	47° 15′ N	122° 27′ W	12	87.2	2.79	9	85.0	3.23	2.2	4.27	19	0.31
Bellingham	WA	USA	48° 45′ N	122° 29′ W	18	100.4	2.21	10	93.3	2.81	7.1	3.63	26	0.030
Summerland	BC	Canada	49° 36′ N	119° 41′ W	6	121.3	2.53	9	106.7	2.00	14.6	3.20	13	< 0.001
Courtenay	BC	Canada	49° 41′ N	124° 59′ W	21	101.0	2.09	5	92.8	2.22	8.2	4.46	24	0.040
Kleena Kleene	BC	Canada	51° 57′ N	124° 52′ W	7	125.4	1.39	3	108.3	7.69	17.1	5.10	8	0.005

[a] First arrival dates reported by consistent historical observers.
[b] First arrival dates estimated from eBird checklists based on temporal occupancy patterns according to the methods of Hurlbert and Liang (2012).
[c] Arrival dates expressed as day of year (DOY) and corrected for leap years; for example, '100′ = 10 Apr.
[d] According to null hypothesis ($P > t$) for Coos Bay and Newport; and null hypothesis ($P < t$) for remaining cities.

best-fitting logistic curve (JMP Version 12, SAS Institute: Cary, NC). The inflection point of each logistic curve corresponded to the date when Rufous Hummingbirds appeared on a majority of checklists (that contained observations of Rufous Hummingbirds) in a particular location and year (Hurlbert and Liang 2012). To reduce variability associated with identifying mean first arrival dates using this method, frequency values calculated from ≤30 checklists in a particular period/location/year combination were excluded from analysis, as were location/year combinations that had usable frequency values for <10 of the 16 time periods. Two additional location/year combinations were excluded from analysis based on poorly fitting logistic curves that resulted in high variability surrounding inflection point estimates. This resulted in 59 usable location/year combinations in the recent time period (Table 1). Mean first arrival dates between time periods were then compared using *t*-tests (Table 1) in the statistical program JMP (JMP Version 12, SAS Institute: Cary, NC).

Climate Data

I used climate data from the High Plains Regional Climate Center (http://climod.unl.edu/) to assess climate changes between time periods at each location in the United States and climate data from the Second Generation of Homogenized Temperatures datasets (available at: www.ec.gc.ca/dccha-ahccd/default.asp?lang=en&n=70E82601-1) to assess climate changes in Canada (Vincent et al. 2012). Mean spring temperature (i.e., mean temperature in Mar–Apr) was used to approximate environmental changes over time and was selected because of its demonstrated impact on the migratory phenology of birds (Gordo 2007) and wide availability in the United States and Canada over the past century. Temperature data were accessed from one to two weather stations nearest each observation location (Fig. 1) that had monthly temperature records available for ≥60 years and spanned the historical (1895–1969) and recent time periods (2006–2015). Years that contained more than five missing dates for either March or April were excluded from analyses. Changes in spring temperature were assessed by location using linear regression (Table 2) and collectively by including location as a random variable using multiple regression (JMP Version 12, SAS Institute: Cary, NC). Changes in first arrival dates in relation to spring temperature were also assessed using multiple regression by including location as a random variable. Temperature data accessed from the United States were converted from degrees Fahrenheit to degrees Celsius for all analyses.

RESULTS

Mean first arrival dates for Rufous Hummingbirds generally followed the expected latitudinal gradient among study sites, with earlier arrivals reported in more southerly areas in each time

TABLE 2. Changes in mean spring (Mar–Apr) temperature at eight locations in North America arranged by latitude.

City	St./Prov.	Latitude	Longitude	Weather Station(s)	Year Range	n^a	Δ Temp.[b]	SE	t	P
Coos Bay	OR	43° 22′ N	124° 13′ W	North Bend Regional Airport	1902-2016	113	0.0038	0.0031	1.22	0.22
Newport	OR	44° 38′ N	124° 03′ W	Newport, Newport 3N	1893-2016	109	0.0050	0.0032	1.55	0.13
Portland	OR	45° 31′ N	122° 41′ W	Portland RFC City, Portland KGW TV	1875-2016	136	0.0054	0.0026	2.06	0.041
Tacoma	WA	47° 15′ N	122° 27′ W	Tacoma City Hall, Tacoma #1	1949-2016	60	0.0338	0.0060	5.67	< 0.001
Bellingham	WA	48° 45′ N	122° 29′ W	Bellingham 2N, Bellingham Intl. Airport	1915-2016	94	0.0090	0.0038	2.38	0.019
Summerland	BC	49° 36′ N	119° 41′ W	Penticton	1909-2015	106	0.0061	0.0035	1.75	0.084
Courtenay	BC	49° 41′ N	124° 59′ W	Comox	1936-2015	79	0.0140	0.0042	3.29	0.002
Kleena Kleene	BC	51° 57′ N	124° 52′ W	Tatlayok Lake	1930-2015	83	0.0006	0.0060	0.10	0.92

[a] Number of years included in analysis; years that contained >5 missing days for either March or April were excluded.
[b] The mean annual change in spring temperature expressed in °C (i.e., the slope of the model: y = spring temp. + error).

period (Table 1). Between time periods, arrival dates changed at six of eight locations (Table 1). Interestingly, hummingbirds arrived later in recent times in the coastal cities of Coos Bay and Newport, Oregon (11 days later and eight days later, respectively; Table 1). In contrast, birds arrived seven, eight, 15, and 17 days earlier in northernmost locations (i.e., Bellingham, WA, and Courtenay, West Summerland, and Kleena Kleene, BC, respectively; Table 1). No differences in mean first arrival dates were noted at locations in Portland and Tacoma. The mean range of first arrival dates reported at each location was 28.5 ± 14.74 SD in the historical period and 19.75 ± 7.30 SD in the recent period. On average, there were 34 days between arrival dates in Portland and Kleena Kleene in the historical period, and 24 days between arrival dates in the recent time period, corresponding to an approximate migratory rate of 21.5 km/day and 30.4 km/day, respectively.

Climate data collectively indicated that temperatures had increased over time in my study region between 1895–2016 ($r^2 = 0.79$, $t = 6.35$, $P < 0.001$). When analyzed by city, a positive estimate for the slope (i.e., associated with a warming spring) was noted for all cities, although a significant trend was only noted in four of the eight cities (Table 2). Climate changes were not apparent in Coos Bay ($P = 0.22$) and Newport ($P = 0.13$), Oregon, or in Kleena Kleene, BC ($P = 0.92$). Overall, mean spring temperatures impacted first arrival dates of Rufous Hummingbirds with birds arriving earlier in years with warmer spring temperatures (slope = –3.08, $r^2 = 0.79$, $t = –4.25$, $P < 0.001$).

DISCUSSION

My results provide a broad-scale perspective on the migratory changes that Rufous Hummingbirds have experienced over the past century in western North America. Historical estimates for mean first arrival dates in the coastal regions of Oregon (i.e, 1–8 Mar; Table 1) are consistent with the earliest arrivals that Bent (1940) reported for Washington State. Campbell et al. (2007) reported that recent migration of Rufous Hummingbirds usually occurs in April along the coast of British Columbia (with a few birds arriving in March) and ~3 weeks later in the interior. Their estimates closely correspond to what I report for the coastal town of Courtenay, BC (3 Apr), and the interior towns of Summerland and Kleena Kleene (17 Apr and 18 Apr, respectively; Table 1).

Climate data (Table 2) are generally consistent with the consensus that temperatures have increased in the Pacific Northwest in the past century by ~0.72 °C (Kunkel et al. 2013, Mote et al. 2014). Warmer springs not being noted in Coos Bay, Newport, and Kleena Kleene may indicate that warming does not always occur uniformly across a region and may be impacted by local environmental and ecological variables (Loarie et al. 2009, Intergovernmental Panel on Climate Change 2014). Earlier arrival dates of birds in years with warmer springs that are reported in this study and by others (Gordo 2007, Lehikoinen and Sparks 2010) and the general trend of warming regional temperature in the past century in the Pacific Northwest (Table 2), indicate that migratory advancements of Rufous Hummingbirds are likely climate-related.

To my knowledge, no one has conducted a site-based study assessing changes in migration dates of Rufous Hummingbirds, so it is difficult to compare the changes in first arrival dates that I report to other studies; however in the eastern United States, climate-related migratory advancements of four, six, 12, and 18 days have been reported for Ruby-throated Hummingbirds by Wilson et al. (2000), Butler (2003), Courter et al. (2013a), and Ledneva et al. (2004), respectively, at locations between 42–44° N. These advancements are generally consistent with those noted in this study at locations between 45–52° N (Table 1) but not with the data for the coastal areas of Coos Bay and Newport where birds arrived 11 and eight days later between time periods. This result may indicate the importance of considering the regional impact of marine systems at these latitudes (Baumann and Doherty 2013, Dobrowski et al. 2013) when interpreting the results of phenology studies. Bograd et al. (2009) reported significant interannual variation in the effects of upwellings and El Niño impacts along the coast of California, associated with unusual coastal temperatures from 1967–2007 and potential impacts to the lifecycles of fish, mammals, and birds. Although hummingbirds are primarily nectarivores, ocean-related processes can impact floral phenology in coastal areas differently than in inland areas and can potentially mask the impacts of temperature-related climate changes (Cayan et al. 2001).

The later first arrival dates that I report in coastal Oregon (Table 1) may also suggest that Rufous Hummingbirds now follow a more direct and inland migratory route to potentially take advantage of more favorable or predictable conditions. This is consistent with my finding that hummingbirds took, on average, 10 fewer days to migrate between Portland and Kleena Kleene in the recent time period. It is also possible that the breeding range of Rufous Hummingbirds is shifting northward (Parmesan and Yohe 2003). Both of these hypotheses rely on the assumption that birds that are less abundant in an area would potentially be reported later. To further support this notion, Sauer et al. (2014) report that declines in populations of Rufous Hummingbirds have been more pronounced in coastal California and Oregon (i.e., 3.7%, 2.9%, declines per year, respectively, from 1966–2013, respectively) than they have been in Washington, British Columbia, and the entire Western BBS Region (–2.1%, –1.9%, and –2.1%, respectively).

La Sorte et al. (2014) report that avian migrants in western flyways generally utilize highly productive, lower elevation passageways during spring migration, but did not directly compare the impacts of coastal vs. inland environments. A tendency of birds to prefer lower elevation passageways during spring migration and the observation that mean migration dates in these locations are being delayed (Table 1) may further support the idea that the migratory route or breeding range of Rufous Hummingbirds has shifted. It is also possible that human development has contributed to changing bird abundances along the Oregon coast (as indicated by later first arrival reports), although based on the adaptability of Rufous Hummingbirds to the habitat heterogeneity associated with urbanizing environments (McGarigal and McComb 1995, Bolger et al. 1997, Healy and Calder 2006), one would predict that birds would be becoming more abundant and would thus be reported earlier. Regardless of mechanism, phenological delays in one region and advancements in another are concerning ecologically, particularly for Rufous Hummingbirds that provide pollination services to a variety of ecosystems during their annual migration (Healy and Calder 2006, McKinney et al. 2012).

I report that it took hummingbirds fewer days (~24) to migrate from Portland to Kleena Kleene in the recent time period (30.4 km/day). This is a slower spring migratory rate than that reported by Supp et al. (2015) for Rufous Hummingbirds between 2008–2013 (i.e., 60.3 km/day), but similar to the daily migratory rates that they report for Broad-billed (*Selaphorus platycercus;* 27.3 km/day) and Black-chinned (*Archilochus alexandri;* 44.0 km/day) hummingbirds, both shorter-distance migrants. This apparent difference may exist because Supp et al. (2015) tracked hummingbirds throughout their entire migratory cycles in North America, and I report migratory rates of Rufous Hummingbirds as they reach, or approach, their breeding grounds. This may suggest that some long-distance migrants decrease their migratory rate as they approach their breeding grounds, perhaps to become more in-sync with environmental conditions en route (Tottrup et al. 2010, Stanley et al. 2012).

To my knowledge, this is the first study that compares mean first arrival dates using historical NABPP records and eBird data (Table 1). This framework could provide the foundation for a nearly endless number of studies designed to assess the impacts of climate change on birds at broad spatial and temporal scales. While some may point out that the methods of detecting mean first arrival dates were different between time periods (i.e., individuals directly reporting first arrival dates historically and mean first arrival dates being calculated from logistic curves in recent times), I argue that a first arrival report from a competent naturalist contributing historical data to the NABPP would, on average, closely approximate when a certain bird species appears on a majority of eBird checklists (i.e., the inflection point of a logistic curve) that are submitted by similarly competent naturalists of today (i.e., vetted eBird participants).

While contemporary contributors may benefit from widely available field guides, range maps, and digital notifications of when to look for and expect first arrivals (Courter et al. 2013b), historical observers also had a robust understanding of the birds in their region (Zelt 2015). For example, Theed Pearse, a lawyer by trade, submitted first arrival records for Rufous Hummingbirds in Courtenay, Canada, for >20 years. He was a long-time member of the American Ornithologists' Union, an honorary member of the Pacific Northwest Bird and Mammal Society, and he self-published the book 'Birds of the Early Explorers in the Northern Pacific' (Pearse 1968). Given the expertise of historical observers and their specified task of identifying first arrivals (Zelt et al. 2012), one could argue that historical first arrival dates would more closely approximate true first arrival dates than extracting mean first arrival dates from eBird checklists. If this is the case, then the comparative method described in this paper would have the tendency to underestimate climate-related advancements in birds. I find this to be preferable to a method that is prone to overestimation, particularly at a time when much of the general public remains skeptical about the effects of climate change (Weber and Stern 2011). Future assessment is also needed to assess how the mean first arrival calculation methods described here approximate other aspects of migration phenology such as mean arrival of a migratory cohort (Sparks et al. 2005, Miller-Rushing et al. 2008).

My results demonstrate a climate-related advancement of Rufous Hummingbirds in western North America, a place where few studies have been conducted compared with the eastern United States and Europe. In addition, I provide a framework for comparing information from two extensive and emerging datasets to better understand the impacts of climate change on bird migration and justification for future studies to investigate the ecological impacts of climate change on birds in coastal vs. inland environments.

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