Examining Seasonal Bird Migration in Relation to Weather, Air Quality, and Radar Data

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Objectives

- **Explore seasonal bird migration in Fort Collins**
- **Explore how air quality, weather, and radar data predict on-the-ground nightly migratory observations**

Background

- Billions of migratory birds move across the continent each spring and fall as they move to and from their breeding grounds.
- While migrating, birds emit species specific nocturnal flight calls (NFCs) to communicate with other, allowing us to track their movements.
- Nightly movements of birds are influenced by weather patterns and can be observed via weather surveillance radar (WSR; see Conclusions).
- Bad air quality in the Pacific Flyway during the 2020 wildfire season was attributed to rerouting and prolonging migration of geese[1], suggesting air quality impacts migratory birds.

Methods

NFC Recording

- Flowerpot recorder (see right): Zoom F6 audio recorder with Lom mikroUši Pro omnidirectional microphone placed on a Fort Collins, CO rooftop.
- Nightly recordings taken from 9/10-10/8 of 2020 for fall migration and 4/1-5/23 of 2021 for spring migration.

Weather, Radar, and Air Quality Data

- Hourly measurements of these data were aligned with hourly counts of NFCs. Air quality is measured as fine particulate matter (PM 2.5), which acts as a measure of smoke intensity in our study.

NFC Analysis

- Flight calls captured on recordings extracted from spectrograms produced in Raven Pro (see below).
- Flight calls were identified based on shape and sound, in comparison to existing libraries of NFCs found on the internet.

Spectrogram example: Long-billed Curlew (*Numenius americanus*; spectrogram and left photo) flight calls and associated audio captured on April 12, 2021 at 01:48. Swainson's Thrushes (*Catharus ustulatus*; right photo) recorded during a heavy migratory movement on the night of May 14, 2021. Over 30 NFCs can be heard in this 35 s recording.

Results

Fall 2020

Variable	Importance Score
Dew Point	5.93
Julian Date	1.42
Temperature	1.02
Migration Traffic Rate	0.67
Time since 1900hr	0.65
PM 2.5	0.53
Wind Speed	0.12
Ceiling Height	-0.01
Wind direction	-0.04

Table 1: Fall 2020 variable importance scores. Values indicate the impact on nightly NFC counts. The further from 0 in either direction the stronger the impact. A total of 708 flight calls were captured in 2020.
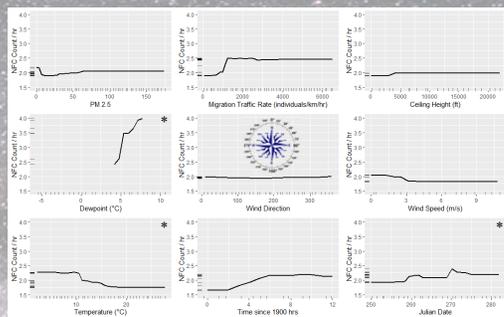

Figure 1: Relationship between nocturnal flight call counts and predictor variables. Lines are derived from estimates from random forest models. An asterisk indicates the three variables with the largest impact: dew point, Julian date, and temperature.

Variable	Actual x̄	+/- SD	Null x̄	+/- SD	t-stat	d.f.	p-value
Dew Point (°C)	4.846	0.099	0.004	0.128	299.90	186.39	<2.2e-16
Julian Date	1.434	0.064	0.008	0.148	88.28	134.26	<2.2e-16
Temperature (°C)	0.964	0.060	-0.014	0.103	81.78	159.41	<2.2e-16
Migration Traffic Rate	0.634	0.046	0.009	0.110	52.24	132.40	<2.2e-16
PM 2.5	0.487	0.034	0.016	0.120	37.71	114.62	<2.2e-16
Time since 1900hr	0.609	0.052	0.026	0.241	23.59	108.04	<2.2e-16
Wind Speed (km/hr)	0.155	0.034	-0.013	0.084	18.66	130.40	<2.2e-16
Wind Direction	0.022	0.024	-0.001	0.123	1.86	106.28	<0.1
Ceiling Height (ft)	-0.018	0.011	0.003	0.042	-4.79	113.13	<5.0e-6

Table 2: T-test analysis of each predictor variable, where the results of 100 replicates of a random forest model were compared against 100 replicates of random forest model where the values of each variable were randomized with respect to time.

Spring 2021

Variable	Importance Score
Dew Point	32.34
Julian Date	21.57
Ceiling Height	8.36
Wind Speed	5.83
Temperature	5.64
PM 2.5	3.04
Time since 1900hr	1.93
Migration Traffic Rate	0.24
Wind direction	-0.63

Table 3: Spring 2021 variable importance scores. Values indicate the impact on nightly NFC counts. The further from 0 in either direction the stronger the impact. A total of 1794 flight calls were captured in 2020.
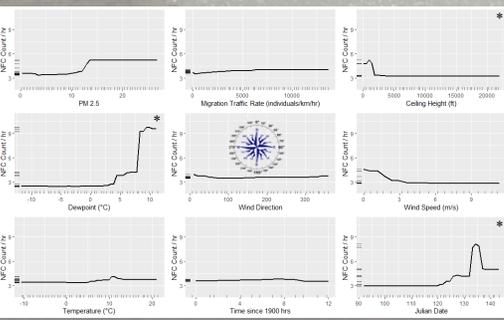

Figure 2: Relationship between spring nocturnal flight call counts and predictor variables. Lines are derived from estimates from random forest models. An asterisk indicates the three variables with the largest impact: dew point, Julian date, and ceiling height.

Variable	Actual x̄	+/- SD	Null x̄	+/- SD	t-stat	d.f.	p-value
Dew Point (°C)	32.075	-0.020	0.809	1.115	232.96	180.65	<2.2e-16
Julian Date	23.111	-0.003	0.840	0.892	188.74	197.29	<2.2e-16
Wind Speed (km/hr)	5.828	-0.065	0.498	0.654	71.71	184.88	<2.2e-16
Ceiling Height (ft)	8.628	0.152	0.554	1.258	61.66	135.98	<2.2e-16
Temperature (°C)	6.709	0.054	0.430	1.093	56.62	128.92	<2.2e-16
PM 2.5	3.616	-0.029	0.410	0.890	37.17	139.26	<2.2e-16
Time Since 1900hr	1.329	-0.093	0.676	0.676	20.59	107.63	<2.2e-16
Migration Traffic Rate	0.612	0.129	-0.101	0.462	14.88	114.23	<2.2e-16
Wind Direction	-0.405	-0.021	0.283	0.872	-4.19	119.60	<5.31e-05

Table 4: T-test analysis of each predictor variable where the results of 100 replicates of a random forest model were compared against 100 replicates of a random forest model where the values of each variable were randomized with respect to time.

Conclusions

- 2.5x more NFCs recorded during spring, over a shorter period.
- Meteorological variables and date best predicted nightly NFC counts with different impacts between seasons, and with dew point having the strongest impact across seasons.
- Decreasing air quality contributed to higher NFC counts, but the mechanism of action is currently unknown.

How might climate change driven wildfires impact migration?

Poor air quality: Cameron Peak fire smoke plume over Horsetooth Reservoir, Fort Collins, CO, Fall 2020.

Integrating air quality with weather variables and nightly WSR should improve the tracking of nightly migratory bird movements.

WSR: Blue/green circles represent birds aloft and are distinctly different from the weather fronts. The embedded QR provides the moving radar map

Improving our ability to predict bird movements aids conservation efforts aimed at reducing hazards in the path of migratory birds.

Migration Forecast: CSU Aeroecology Lab migration forecast for 9/8/2021. These forecasts are used to issue 'Lights Out' alerts to reduce light pollution driven mortality in our cities.

Next Steps

- Replicate study across time and space to understand how widespread are results might be.
- Explore these patterns for different species, families, and orders.

References

1. Overton, C. T., Lorenz, A. A., James, E. P., Ahmadov, R., Eadie, J. M., Mcduie, F., Petrie, M. J., Nicolai, C. A., Weaver, M. L., Skalos, D. A., Skalos, S. M., Mott, A. L., Mackell, D. A., Kennedy, A., Matchett, E. L., and Casazza, M. L. 2022. Megafires and thick smoke portend big problems for migratory birds. *Ecology* 103(1):e03552. 10.1002/ecy.355