Red-Tailed Hawk Sensor Analysis: Unveiling Seasonal Movement Insights

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1 Introduction

This study addressed a significant gap in our understanding of the movement ecology of red-tailed hawks, particularly in the western United States. While these raptors were emblematic of the wild and were often used as models in research due to their abundance, little was known about their post-rehabilitation success and subsequent contributions to ecological systems. By focusing on post-rehabilitation studies, the sponsor's organization WNY Raptor and Wildlife Care Inc. aimed to elucidate the critical factors that influenced the survival and behaviors of red-tailed hawks in the wild after rehabilitation efforts.

The anticipated contributions of this study extended beyond the immediate scope, aiming to influence future management practices in the release of rehabilitated birds. As red-tailed hawks could serve as models for research due to their prevalence, our findings aspired to guide the establishment of release criteria and ensure the successful nesting, reproduction, and perpetuation of their species in the wild.

In the pages that followed, we detailed the methodologies involving exploratory and descriptive analysis of recently released raptor data, statistical tests, and implications for our study, offering a nuanced understanding of the post-rehabilitation journey of red-tailed hawks and its broader implications for wildlife conservation.

2 Data Description

2.1 Birds Profile

WNY Raptor gathered data to understand the behavior of rehabilitated red-tailed hawks post-release in Western New York. In this section, we conducted a thorough examination of the profiles of the three data-ready birds provided by Dr.Clabeaux, providing comprehensive insights into the distinctive traits and characteristics exhibited by the red-tailed hawks:

Table 1 Bird Profile Table

Bird ID	***Maverick***	***Moe***	***McDonnell***
Total ping(s)	6265	892	12610
Age	Juvenile	Juvenile	Adult
Injury	Orphaned; no injury	Orphaned; no injury	Lead poisoning
Transmitter Type	Druid Omni 3G GPS/GSM	Druid Omni 3G GPS/GSM	LEGO 4G-A ECL26
Rescue Date	20 Jun 2021	6 Jun 2022	2 Feb 2023
Release Date	Sep 2021	21 Sep 2022	29 Apr 2023
Last Date of Detection	19 Sep 2023	05 Dec 2022	12 Oct 2023
Data Source	MoveBank	MoveBank	Ecotopia

Originally, we had intended to conduct an analysis based on our understanding of the field, anticipating that adult hawks would exhibit more migratory and active behavior compared to their juvenile counterparts. However, the available data revealed a limitation. As seen from table 1, there were only six months of data recorded for McDonnell. As a result, conducting a meaningful analysis based on age-related patterns is not viable.

Upon observation, McDonnell's sensor exhibited a significant variation in ping responses. This emphasizes the importance of considering a potential switch to a 4G GPS sensor for future research.

2.2 *Data Summary*

As part of our Exploratory Data Analysis, we focused on three key movement attributes - Ground Speed, Altitude, and Heading/Course - extracted from our original datasets. Additionally, we explore Power Access (Nasa.gov) to retrieve external weather information at the specific coordinates - longitude and latitude - of the birds. The table 2 below presents the attributes and their respective definitions:

Table 2 Attributes and Definitions

Attribute(s)	***Definition(s)***
Ground Speed	Speed measured against ground (m/s)
Altitude & Coordinate	Latitude, longitude & Height above sea level (m)
Heading/Course	Direction in which the tag is moving, in decimal degrees clockwise from North
External Light Intensity	Light intensity as lx
External Temperature	Temperature in Celsius
External Precipitation	Total depth of rainwater (mm) during 24 hours (mm/day)
External Wind Speed	The min. hourly wind speed at 50m above the earth's surface (m/s)
External Humidity	Weight (amount) of vapor contained in a unit weight (amount) of air (g)

2.3 *Missing Data*

At the heart of the tracking and movement data collection is the utilization of Druid Omni 3G GPS/GSM transmitters or 4G transmitters. These state-of-the-art devices are securely affixed to the red-tailed hawks, offering a continuous stream of location information. The transmitters not only enable precise tracking but also contribute to a comprehensive understanding of the hawks' post-rehabilitation movements in the wild.

However, an initial analysis of the data obtained from the two data platforms displays a rather inconsistent and varying timeline of transmission data for raptors release from WNY care. The sensors used for tracking and transmitting the location, speed, and altitude of the released raptor are solar-powered. Hence, the initial battery status and location of the bird in the wild can impact the battery life and sensor functionality.

Table 3 Missing Data Analysis

Bird	*Maverick*	*Moe*	*McDonnell*
Days since released	831 (6265 obs.)	445 (892 obs.)	224 (12626 obs.)
Number of days transmitted	300	74	165
Perc. of days transmitted (%)	36.1	16.62	73.6

From table 3 we gather that the underlying transmitter technology affects the overall transmitted signals. The raptor released recently in 2023, McDonnell, with 4G sensors with a relatively shorter timeline post rehabilitation displays a higher percentage of days transmitted. The release location and probability of survival based on that can also impact signal trends other than the tracking technology used.

3 Exploratory Data Analysis

The data exploration for the three red-tailed hawks – Maverick, Moe, and McDonnell – provides a captivating narrative of their post-rehabilitation journeys. By examining their signal locations and timelines, we gained valuable insights into their movements, habitat preferences, and the success of the rehabilitation efforts.

3.0.1 Overall bird signals

Collectively, the overall signals for Maverick, Moe, and McDonnell underscored a remarkable pattern of prolonged residency. The birds showcased an ability to stay at their respective locations for extended periods, indicative of a careful and patient approach to adapting to the wild. These shared themes highlight the success of the rehabilitation efforts, preparing the red-tailed hawks for sustained and thriving lives in their natural habitats as shown in Fig 1.

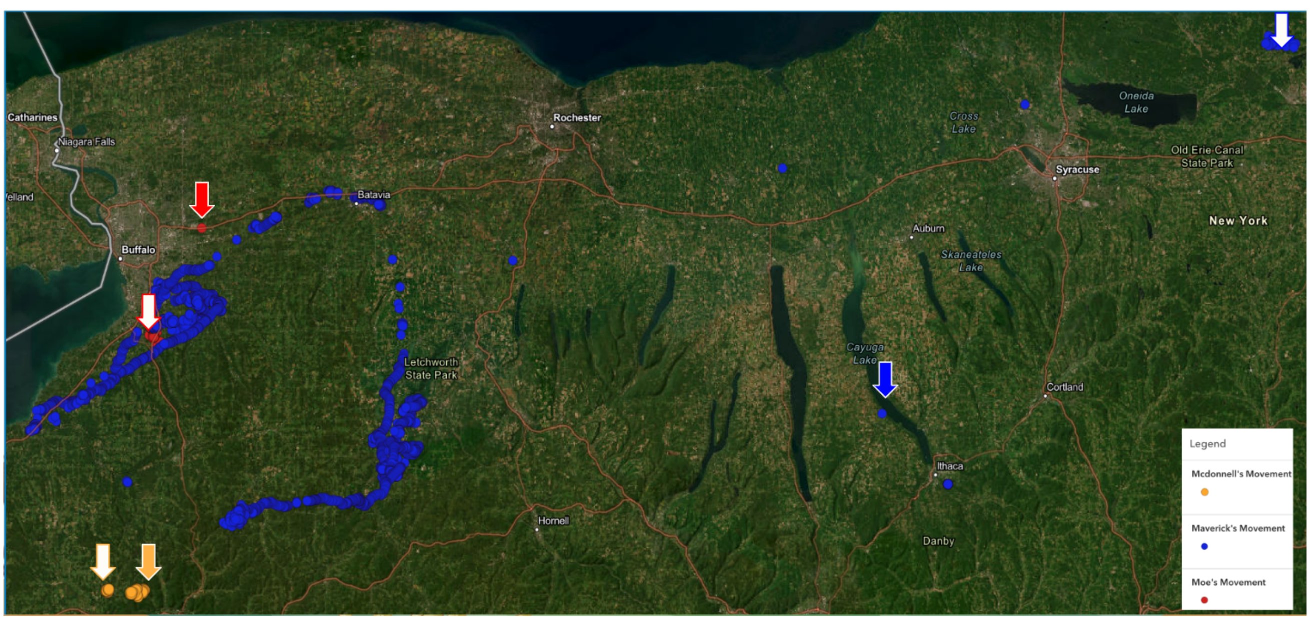

Fig 1 Overall bird signals

In Fig 1, the three birds — Maverick, Moe, and McDonnell —tell their stories through arrows of different colors. Maverick starts its journey with a straightforward blue arrow, pointing from where it all began. The blue arrow represents the beginning of Maverick's exploration. The final stop is marked by a white arrow with a blue border. Moe's journey kicks off with a noticeable red arrow, highlighting the starting point. The journey concludes with a white arrow outlined in red, indicating Moe's decision last ping recorded. McDonnell begins its exploration with an orange arrow, representing the starting point. The orange arrow tells the tale of McDonnell's initial signal into the wild. The journey ends with a white arrow surrounded by an orange border, symbolizing a prolonged stay.

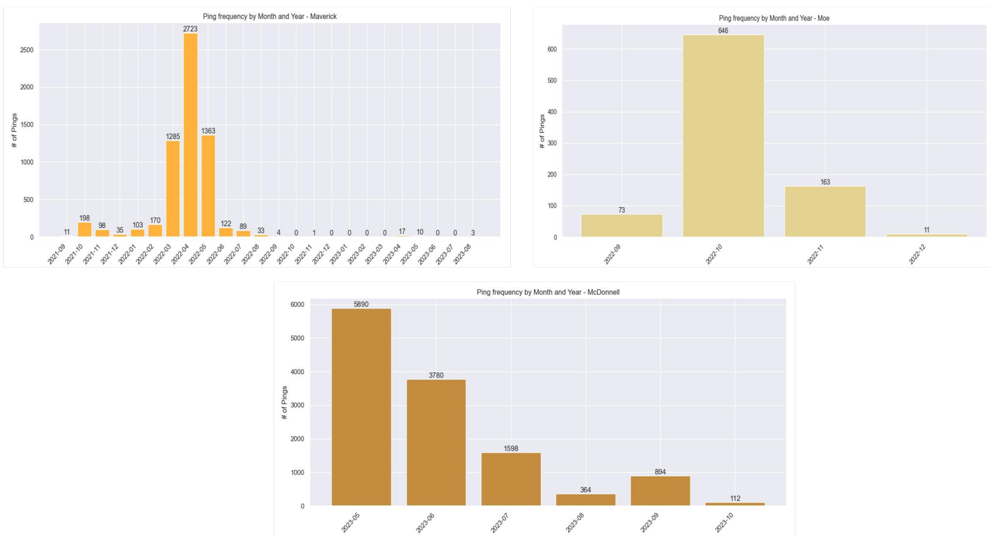

Fig 2 Signal density by month

In Fig 2, we observed a skewed distribution for all three birds. The distribution trend could be attributed to the season, location, bird's health, and battery life of the device tethered.

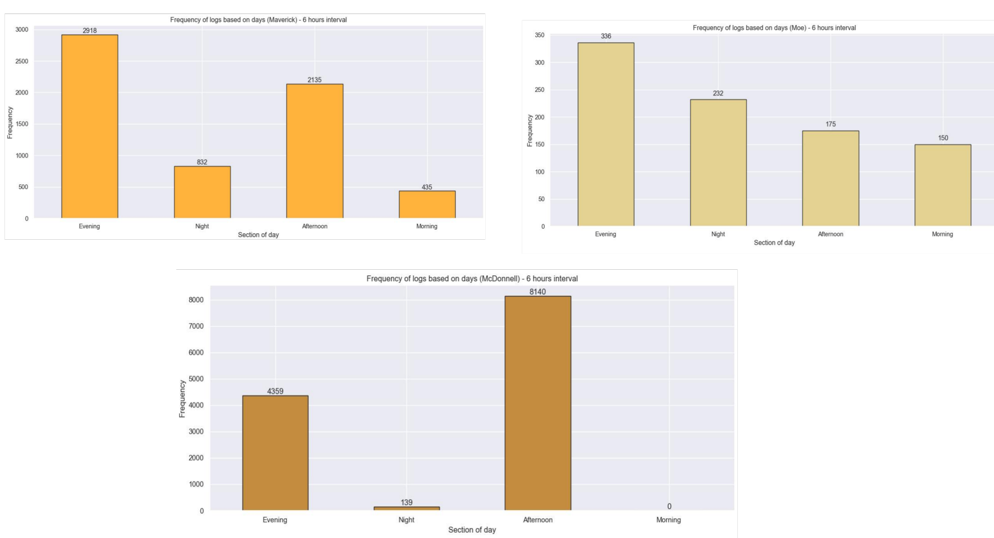

Fig 3 Signal density by section of day

From Fig 3, we gathered that these birds are rather active towards evening and night. This observation goes with commonly found red-tailed hawks in western New York.

3.0.2 Birds signals by season

Maverick's seasonal movements exhibited a distinct pattern, notably marked by increased activity during the migratory months of March, April, and May. This behavior aligned with typical avian patterns, suggesting that Maverick was responsive to environmental cues associated with migration. During the colder winter months from September 2021 through February 2022, Maverick's mobility decreased, indicating a more sedentary phase. This aligned with the natural tendency of birds to conserve energy in colder weather. These seasonal signals affirmed Maverick's ability to synchronize its movements with the changing seasons, showcasing a successful integration into the wild. As shown in Fig 4.

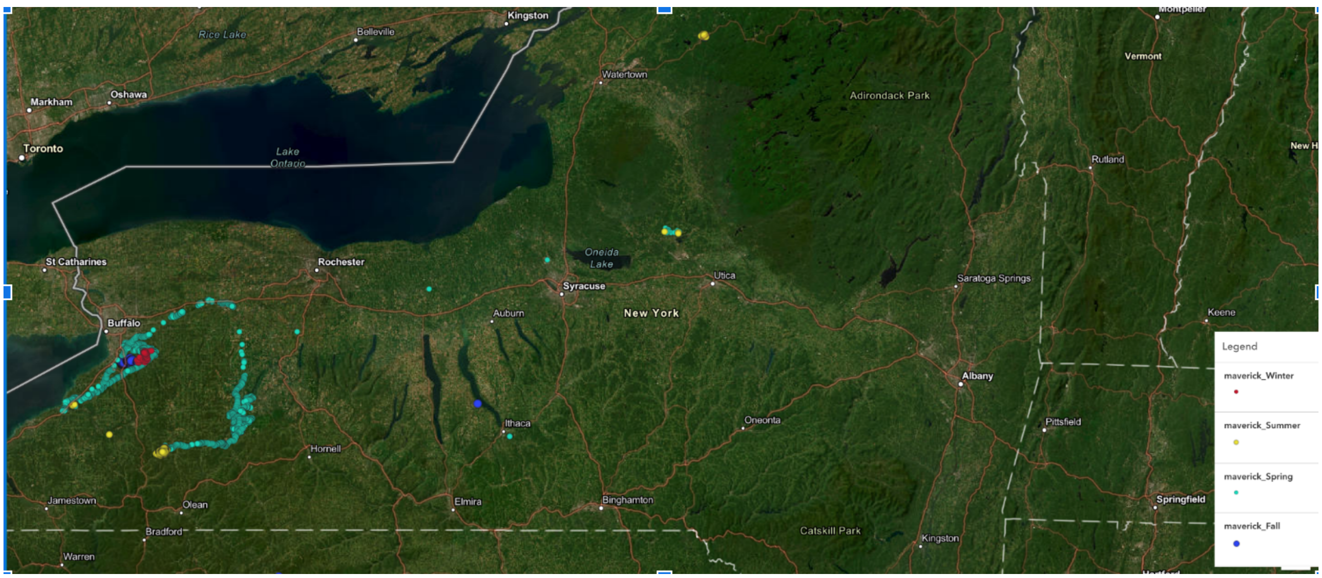

Fig 4 Maverick's seasonal signals

The Fig 5 shows a detailed distribution graph based on the seasons the raptors spent post-rehabilitation. We notice that there is more movement during the spring for Maverick and McDonnell. There is a similar pattern in these two cases. Since Moe was only transmitting for two seasons, we see there was a surge in signals followed by a very small fraction the following season.

Similar to Maverick, Moe's seasonal signals reflect an exploratory nature. The noticeable increase in movement during migratory months suggested a responsiveness to environmental cues associated with seasonal changes. Moe's decision to explore more during these months aligns with the instinctive behaviors of birds, particularly during periods conducive to migration. Additionally, Moe's decreased mobility during colder winter months indicates an adaptation to the environmental conditions, emphasizing the bird's ability to navigate and adjust its behavior in response to seasonal variations. Moe made only signaled only in the winter and fall months. This is shown in Fig 6.

As McDonnell embraces the migratory months, the visual exploration of McDonnell's seasonal movements is unfolded with an increase in signals from spring. This vibrant representation aligns with the broader bird migration patterns, signifying a period of exploration, territorial establishment, or preparation for the breeding season. However, as McDonnell approaches its first

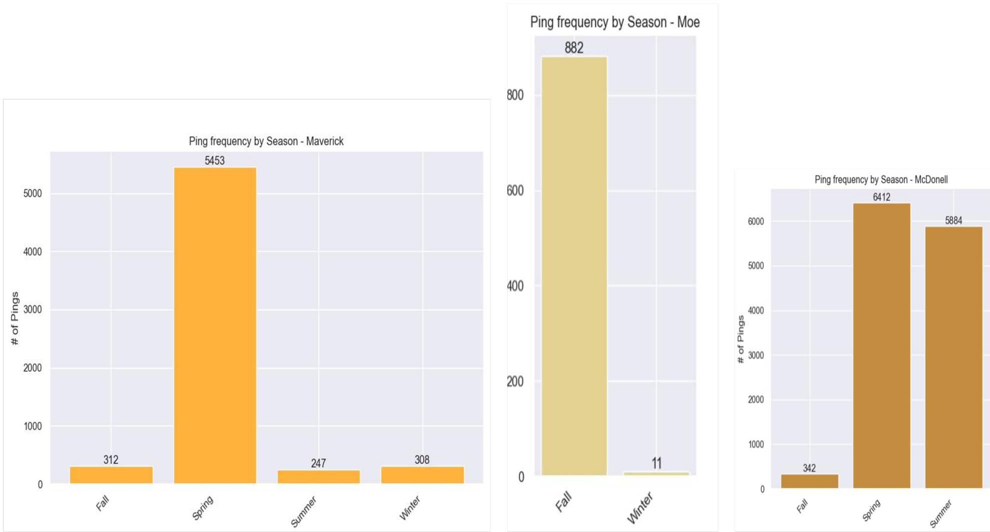

Fig 5 Signal density by season

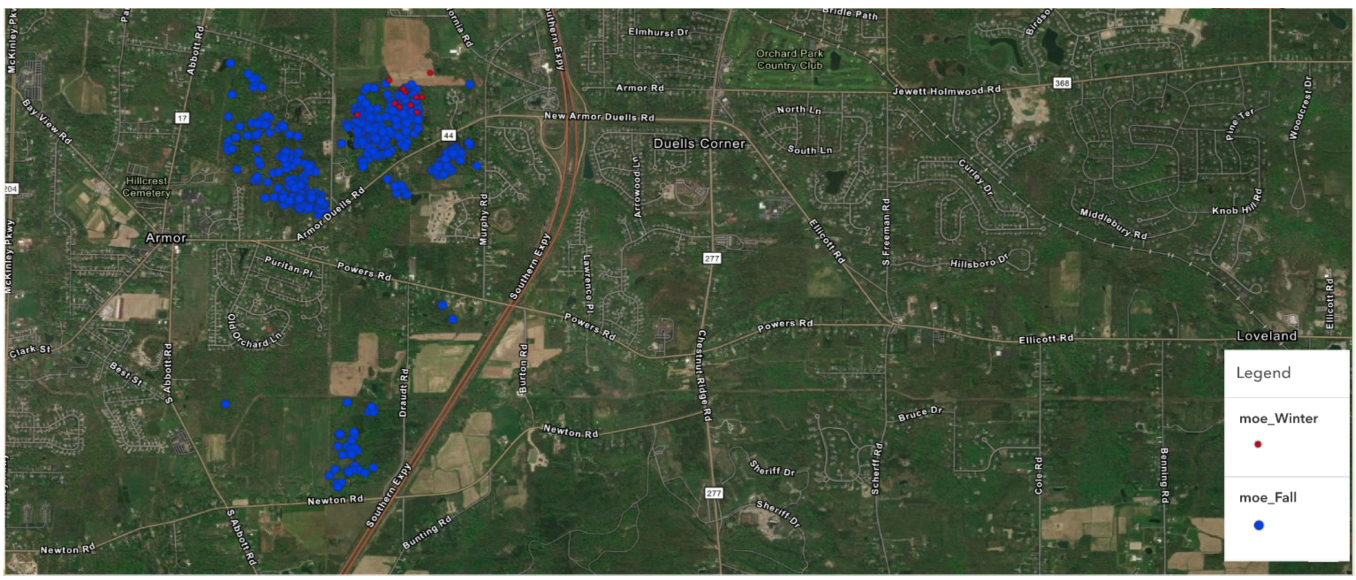

Fig 6 Moe’s seasonal signals

winter since release, the winter quadrant remained a blank canvas, devoid of recorded data as can be shown in Fig 7.

Common themes emerge across all three birds. The increased activity during migratory months and decreased mobility in colder seasons underline their collective ability to synchronize with seasonal shifts. These shared behaviors provide valuable insights into their successful integration into respective habitats, showcasing resilience and adaptability in response to the changing natural rhythms.

4 Statistical Testing on Seasonality of Movement Variables of Maverick

This section delves into the use of classical Hypothesis Testing to understand if there were any differences in how Maverick moved based on seasonality. To be able to quantify the bird’s move-

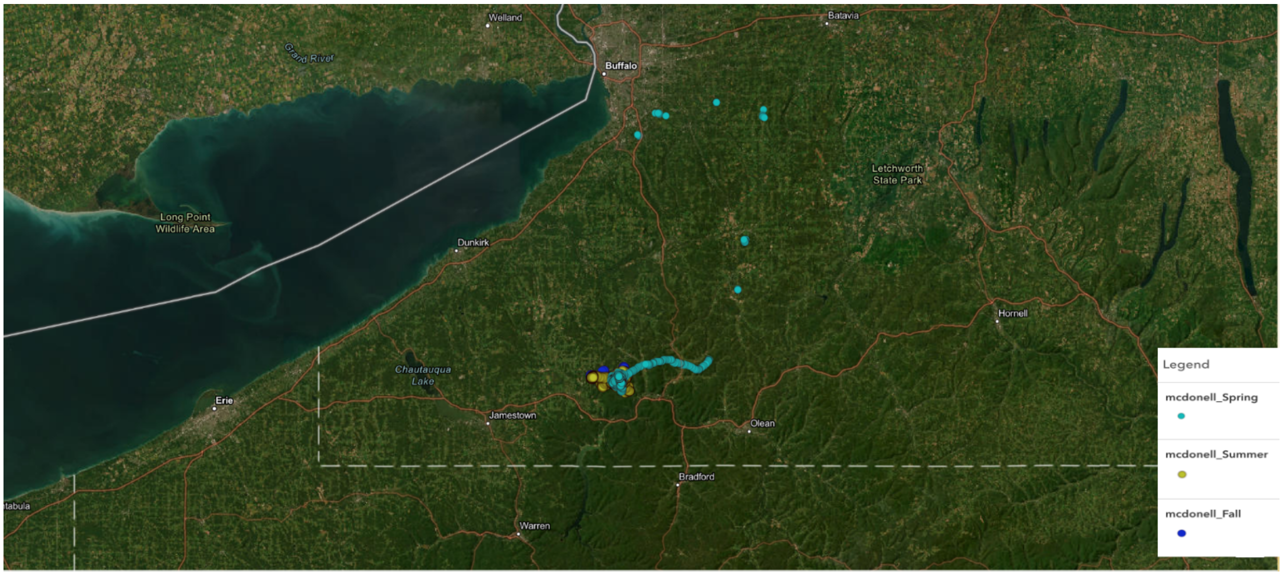

Fig 7 McDonnell's seasonal signals

ment, three variables namely speed, heading, and altitude were chosen as the variables of interest and were each grouped into the four main weather seasons in a bid to analyze if the daily mean movement of a Maverick varied between seasons for each variable. The tests employed were the Kruskal Wallis Test and the Wilcoxon Ranked Test.

4.1 Mavericks's Test

This subsection details the experimental design and setup in testing if there was a seasonal variation in the movement of Maverick. A sample of 59 Rows of the daily means of each variable collected from the 3G sensor was used to conduct a series of hypothesis tests at $\alpha = 0.05$.

4.1.1 Test on Speed

In a bid to understand if speed varied across seasons during the flight period of Maverick, the experimental design was set up:

Ho: There is no difference in the average daily mean speed of Maverick across seasons
Ha: This a difference in the average daily mean speed of Maverick across seasons

Table 4 Results of Kruskal Wallis Test on Maverick's Ground Speed

Test Statistic	***P-Value***	***Conclusion***
48.90	1.37e-10	Reject Ho, Conduct Wilcoxon Ranked Test

Since we rejected the null hypothesis, the Wilcoxon Ranked Test was used to understand which seasons differed in daily mean speed. The table 5 below summarizes the experimental setup and results of the test.

Ho: There is no difference in daily mean speed between Season A and Season B
Ha: There is a difference in daily mean speed between Season A and Season B

Table 5 Results of Wilcoxon Ranked Test on Maverick's Ground Speed

Season A	*Season B*	*Test Statistic*	*P-Value*	*Conclusion*
Spring	Summer	384.00	0.00	Reject Ho
Spring	Fall	369.00	9.82e-05	Reject Ho
Spring	Winter	206.50	3.03e-07	Reject Ho
Summer	Fall	590.00	0.06	Fail to Reject Ho
Summer	Winter	371.50	0.00	Reject Ho
Fall	Winter	371.50	0.19	Fail to Reject Ho

4.1.2 Test on Heading

In a bid to understand if heading varied across seasons during the flight period of Maverick, the experimental design was set up:

Ho: There is no difference in the average daily mean heading of Maverick across seasons
Ha: This a difference in the average daily mean heading of Maverick across seasons

Table 6 Results of Kruskal Wallis Test on Maverick's Heading

Test Statistic	*P-Value*	*Conclusion*
53.96	1.14e-11	Reject Ho, Conduct Wilcoxon Ranked Test

Since we rejected the null hypothesis, the Wilcoxon Ranked test was used to understand which seasons differ in daily mean heading. The table 7 below summarizes the experimental setup and results of the test.

Ho: There is no difference in daily mean heading between Season A and Season B
Ha: There is a difference in daily mean heading between Season A and Season B

Table 7 Results of Wilcoxon Ranked Test on Maverick's Heading

Season A	*Season B*	*Test Statistic*	*P-Value*	*Conclusion*
Spring	Summer	152.00	6.25e-05	Reject Ho
Spring	Fall	258.00	0.00	Reject Ho
Spring	Winter	9.00	1.05e-07	Reject Ho
Summer	Fall	53.00	0.27	Fail to Reject Ho
Summer	Winter	31.00	0.06	Fail to Reject Ho
Fall	Winter	39.00	0.04	Reject Ho

4.1.3 Test on Altitude

In a bid to understand if altitude varied across Seasons during the flight period of Maverick, the experimental design was set up:

Ho: There is no difference in the average daily mean altitude of Maverick across seasons
Ha: This a difference in the average daily mean altitude of Maverick across seasons

Table 8 Results of Kruskal Wallis Test on Maverick's Altitude

Test Statistic	***P-Value***	***Conclusion***
65.83	3.33e-14	Reject Ho, Conduct Wilcoxon Ranked Test

Since we rejected the null hypothesis, the Wilcoxon Ranked Test was used to understand which seasons differed in daily mean altitude. The table 9 below summarizes the experimental setup and results of the test.

Ho: There is no difference in daily mean Altitude between Season A and Season B
Ha: There is a difference in daily mean Altitude between Season A and Season B

Table 9 Results of Wilcoxon Ranked Test on Maverick's Altitude

Season A	***Season B***	***Test Statistic***	***P-Value***	***Conclusion***
Spring	Summer	390.00	0.00	Reject Ho
Spring	Fall	185.00	1.27e-07	Reject Ho
Spring	Winter	245.00	1.36e-06	Reject Ho
Summer	Fall	83.00	1.42e-11	Reject Ho
Summer	Winter	91.00	2.05e-09	Reject Ho
Fall	Winter	701.00	0.16	Fail to Reject Ho

5 Result and Inference

The result of statistical tests on Maverick shows some interesting observations by season; the speed varies between spring and remaining seasons with ground speed being the highest during spring. Another inference from the test shows minimal to no change in the Maverick's speed for fall and winter. The result obtained for the course of direction for Maverick should be inferred with a high possibility of filler signal transmission as in observation we find the extremely high occurrence of straight northbound movement with no degree calibration. The course shows a similar p-value to speed implying most amount of movement recorded in spring than in other seasons.

6 Conclusion and Next steps

In conclusion, our project has shed light on the intricate behavior and migration patterns of avian species spanning from northern to central America. Despite encountering significant data limitations, particularly in the tracking process influenced by the type of banding equipment, we have gleaned valuable insights. The utilization of advanced transmitters, such as the McDonnell with the Druid 4G sensor, has demonstrated enhanced signal throughput, showcasing the importance of technology in overcoming obstacles in avian tracking.

The prolonged signals observed in our study indicate extended stays in specific locations, suggesting a remarkable degree of acclimatization and comfort within the birds' chosen habitats. This behavior aligns with their ability to establish territories, locate suitable nesting sites, and find abundant food sources. Notably, red-tailed hawks exhibit not only territorial behavior but also a keen ability to identify specific roosting locations within their habitats.

It is crucial to interpret the findings of our study in the context of individual bird behavior, as there is limited correlation among the observed patterns, and the timeline overlap in the western NY area is restricted. Furthermore, insights from domain experts highlight the potential for improved results by increasing rehabilitation time for juveniles and injured raptors. In addressing data limitations and leveraging technological advancements, future research can delve deeper into the complex lives of these avian species, contributing to a more comprehensive understanding of their behaviors and movements.