Cyclical Pattern Detected in Northern Harrier Migration Counts at Some Pennsylvania Hawk Watches

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INTRODUCTION

Since the 1930s, hawk watches have played a critical role in quantifying raptor populations and their trends (Bednarz et al. 1990). Migration counts have documented declines in species such as Bald Eagles (*Haliaeetus leucocephalus*), Peregrine Falcons (*Falco peregrinus*), and American Kestrels (*Falco sparverius*) (Bednarz et al. 1990, Farmer and Smith 2009) and more recently rebounds in Bald Eagles and Peregrine Falcons (Oleyar et al. 2021). Today, scientists utilize hawk watch data and other resources such as Audubon's Christmas Bird Count to understand the continent-wide conservation status of raptors (Oleyar et al. 2021).

One regular migrant past Pennsylvania watch sites is the Northern Harrier (*Circus hudsonis*), a medium-sized grassland raptor that primarily consumes small mammals and birds (Zagorski and Swihart 2020). Despite their generalist diet, their fecundity has been directly linked to cyclical vole populations, with more offspring produced when voles are plentiful, especially at northern latitudes (Hamerstrom 1985). Despite this cyclical offspring boost, Northern Harriers have been declining on eastern migration counts for the past 10 years or longer (Oleyar et al. 2019). Moreover, the Pennsylvania Game Commission has listed the Northern Harrier as threatened due to significant habitat loss throughout the state (Gross 2014).

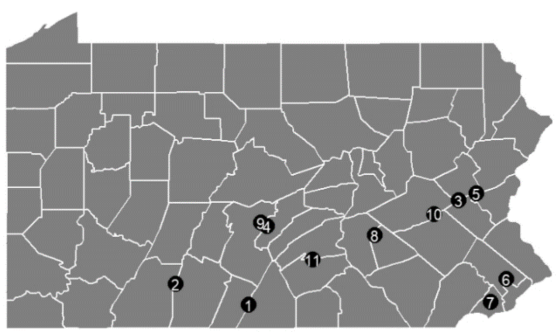

Fig. 1. PA hawk watches selected for study; map created in R version 3.6.0 (R Core Team 2019) using ggplot, maps, ggmap, and mapdata programs (Wickham 2009, Kahle & Wickham 2013, Becker et al. 2018)

Like many raptors, Northern Harriers are partial migrants, meaning that not every individual migrates in the fall. In addition, harriers are broad-front migrants, e.g., they are less likely to be diverted by migration corridors, leading to low counts at inland hawk watches (Bildstein 2006). In the east, harriers typically fly along the Atlantic coast or the Great Lakes before turning south (Bolgiano and Grove 2022). Regardless of lower numbers at many inland sites, recent research suggests that harriers have a four-year cyclic migration pattern that is consistent between five hawk watches from New Jersey to Minnesota, including Hawk Mountain in Pennsylvania (Schimpf et al. 2020). However, there has been minimal investigation of whether this four-year cycle occurs at the other hawk watches in the region, such as the many hawk watches scattered across Pennsylvania.

We predict that if cycles occur across the wider region of eastern states, then four-year cycles should be occurring consistently among sites within a smaller region, e.g., a state or province, as well. To investigate if a cyclical migration pattern occurs across Pennsylvania, we used three data sources: migration count data from 11 Pennsylvanian hawk watches; Christmas bird Count data (CBC); Winter Raptor Survey data (WRS). Because previous research has demonstrated that harrier fecundity has a cyclical pattern, we predict that higher migration counts will be positively correlated with higher counts of immature Northern Harriers.

METHODS

To examine possible cycles in hawk migration counts, we downloaded count data from 11 watch sites across Pennsylvania from HMANA's web database (hawkcount.org) for fall migrations from 1990 to 2021. All sites were in southern counties of Pennsylvania (Fig. 1). We included only hawk watches with over three hundred observer-hours and consistent annual effort from 1990 to 2020 (Table 1). To adjust for effort, we divided all annual counts by hours spent observing. We log-transformed migration counts and then detrended the data through R's pracma package (Borchers 2021). We then ran temporal autocorrelation functions on the adjusted migration count years (birds per hour) for one- to six-year lags (R Core Team, 2022).

To analyze harrier population cycles in Pennsylvania during winter, we compiled PA CBC data from 1993 to 2021 and PA WRS data from 2001 to 2021 (National Audubon Society 2021). These two survey methods differed from each other: observers in the WRS identified harriers by sex and age when possible, whereas CBC observers did not. For the CBC data, we added together Northern Harrier counts from all sites across PA, then divided this by the total hours of effort across the entire state per year. We ran temporal autocorrelation functions for both the CBC and WRS data following the same procedure as the hawk watch data. We compared the percent immature in WRS to the total number of harriers observed using a linear regression. Percent immature was calculated by dividing the number of immature harriers by the total number of adult and immature harriers. We also compared the percent immature to the adjusted harrier migration count from Hawk Mountain Sanctuary (HMS) using a linear regression. Before running the correlation, the adjusted HMS count was log transformed to ensure normality. All statistical procedures were performed in R 3.6.2 (R Core Team, 2019).

RESULTS

From 1990 to 2021, the average Northern Harrier migration count per site varied from 53 to 242 migrants for the eleven sites (Table 1). The average annual count of all eleven sites combined was 100.5 harriers per year for each site (**σ =** ±55.4 birds).

Table 1: Average Northern Harrier count and effort per year from 1990 to 2020 at 11 PA hawk watches, ordered by harriers per hour. *The average for all sites = 100.5 birds = ± 55.4. Table created in R version 3.6 (R Core Team 2019) using the gt program (Iannone et al. 2021).*

HAWK WATCH	Average sightings per fall	Avg hrs observed per fall	Avg. sightings/hr
Tuscarora Summit	75	324.5	0.231
Waggoner's Gap	242	1073	0.225
Little Gap	110	551.7	0.199
Bake Oven Knob	119	781.5	0.152
Rose Tree Park	71	487.3	0.146
Second Mountain	122	841.4	0.145
Stone Mountain	60	414.3	0.145
Militia Hill	63	447.3	0.141
Jacks Mountain	53	386.4	0.137
Hawk Mountain	133	1029.8	0.129
Allegheny Front	57	789	0.072

A significant four-year cycle was found for three of the eleven PA fall watch sites (Table 2, Fig. 2). Among the sites, we observed a significant four-year cycle at Hawk Mountain Sanctuary (HMS), Rose Tree Park, and Stone Mountain (Fig. 2, $p < 0.05$, autocorrelation coefficient = 0.422, 0.227, 0.182, respectively). The higher correlation coefficient at HMS suggests the cycle was stronger at HMS compared to Rose Tree and Stone Mountain. There was also a significant three-year cycle or lag at Jack's Mountain and Tuscarora Summit (Fig. 2, $p < 0.05$, acf = 0.454, -0.178). None of the other watch sites showed evidence of a significant cycle in harrier numbers. The migration data also show that the cycle of peak years appears to have decreased or dampened in amplitude since 2008 (Fig. 2, Table 2).

Christmas Bird Counts for all PA count circles for the period 1993 to 2021 showed a significant four- and five-year lags (Fig. 3, $p < 0.05$, autocorrelation coefficient = 0.236, 0.287). However, the data from the Winter Raptor Survey (WRS) from 2001 to 2021 did not show any cyclical pattern at either two-, three-, or four-year periods ($p > 0.05$).

From 2001 to 2021, the average annual proportion of immature harriers was 22.3 % (**σ =** ±6%). There was a significant correlation between percent immature and the total harriers counted each year on WRS (Pearson's correlation test, $t = 2.211$, $df = 19$, $p = 0.039$). However, there wasn't a significant relationship between the proportion of immature harriers annually and total harrier migration counts at HMS (Pearson's correlation, $t = 0.67288$, $df = 19$, $p = 0.51$). Similarly, there was not a significant cycle detected for the proportion of harriers recorded as immature harriers on migration counts at HMS ($p<0.05$).

DISCUSSION

Five of 11 Pennsylvania autumn hawk watch sites show a significant three or four-year cycle for Northern Harriers as was reported by Schimpf et al. (2020) for a multi-state region (Fig. 2). Similarly, early-winter Northern Harrier populations in Pennsylvania as sampled by Christmas Bird Counts also demonstrated evidence of cyclical patterns coinciding with migration cycles (Fig. 3). However, mid-winter counts such as Winter Raptor Surveys showed no cyclical pattern in our analysis. Furthermore, our prediction that there would be higher counts of immature Northern Harriers wintering or migrating in peak years was not supported in this study.

We predicted that the four-year cycle would be evident at most PA hawk watches, which was not shown in this study. While some sites showed a cyclical count, as did the Christmas Bird Counts, we suspect that variations in weather and effort or harrier broad-front migration behavior could be influencing detection of cycles in migrant harriers at many migration sites, particularly where harriers occur in low numbers. Hawk watches varied greatly in effort hours across the state as well, which could affect counts of this rare, widely dispersed, and unpredictable migrant (Table 1).

Harriers can be difficult to spot and tend to fly low in migration (Bildstein 2006). They also are often the first or last migrant of the day and will fly on rainy or foggy days which can make them less likely to be detected (Bildstein 2006). Additionally, harriers are less apt to concentrate in migration and could be more likely to be missed than some raptors (Bildstein 2006). Because more harriers collect along coastal migration routes in the eastern US, e.g. , Cape May, New Jersey (hawkcount.org), this study should be repeated at hawk watches along the Atlantic coast or in spring sites in the Great Lakes.

The lack of pattern or weak pattern of cycles detected at some watch sites could also be explained by the decreasing numbers of harriers in the East in recent years (Oleyar et al. 2019). Data from 2009-2019 demonstrate that harrier sightings are declining at 51% of eastern hawk watches (Oleyar et al. 2019). The overall population decrease may have decreased the amplitude of any population cycle (Bolgiano and Grove 2022) and may explain the reduction in cycles in recent years.

In comparison to our analysis of hawk watch sites, only one of two metrics of wintering harriers showed a cyclical pattern: the Christmas Bird Count (Fig. 3). This may be due to more observer hours in the Christmas Bird Count and wider geographic coverage than the Winter Raptor Survey. Also, Christmas Bird Counts are conducted early in the winter as compared to Winter Raptor Surveys which occur mid-winter, and so each has a different distribution of raptors across the state. Bolgiano and Grove found a higher number of harriers in the WRS compared to the CBC, especially in the Susquehanna River Valley (Fig. 3, Bolgiano and Grove 2022). Further research into winter harrier movements is needed to understand this phenomenon. Perhaps the CBC counts are influenced more by the population of migrating harriers moving through PA than the later WRS is.

These results may also be impacted by the relatively small population of harriers in our state. Areas with a higher percentage of grassland and marshy habitat, such as Ohio and coastal NJ, tend to have higher percentages of wintering harriers than most of PA (Bolgiano and Grove 2022). The lower overwintering population may explain why we did not find a consistent cyclical trend in winter. A pattern might be more evident if we analyze raptor data from a state with a higher wintering harrier population. With increasing impacts of climate change, some species are wintering at more northern latitudes (e.g., Red-tailed [*Buteo jamaicensis*] and Rough-legged Hawks [*Buteo lagopus*], Paprocki et al. 2014, 2017).

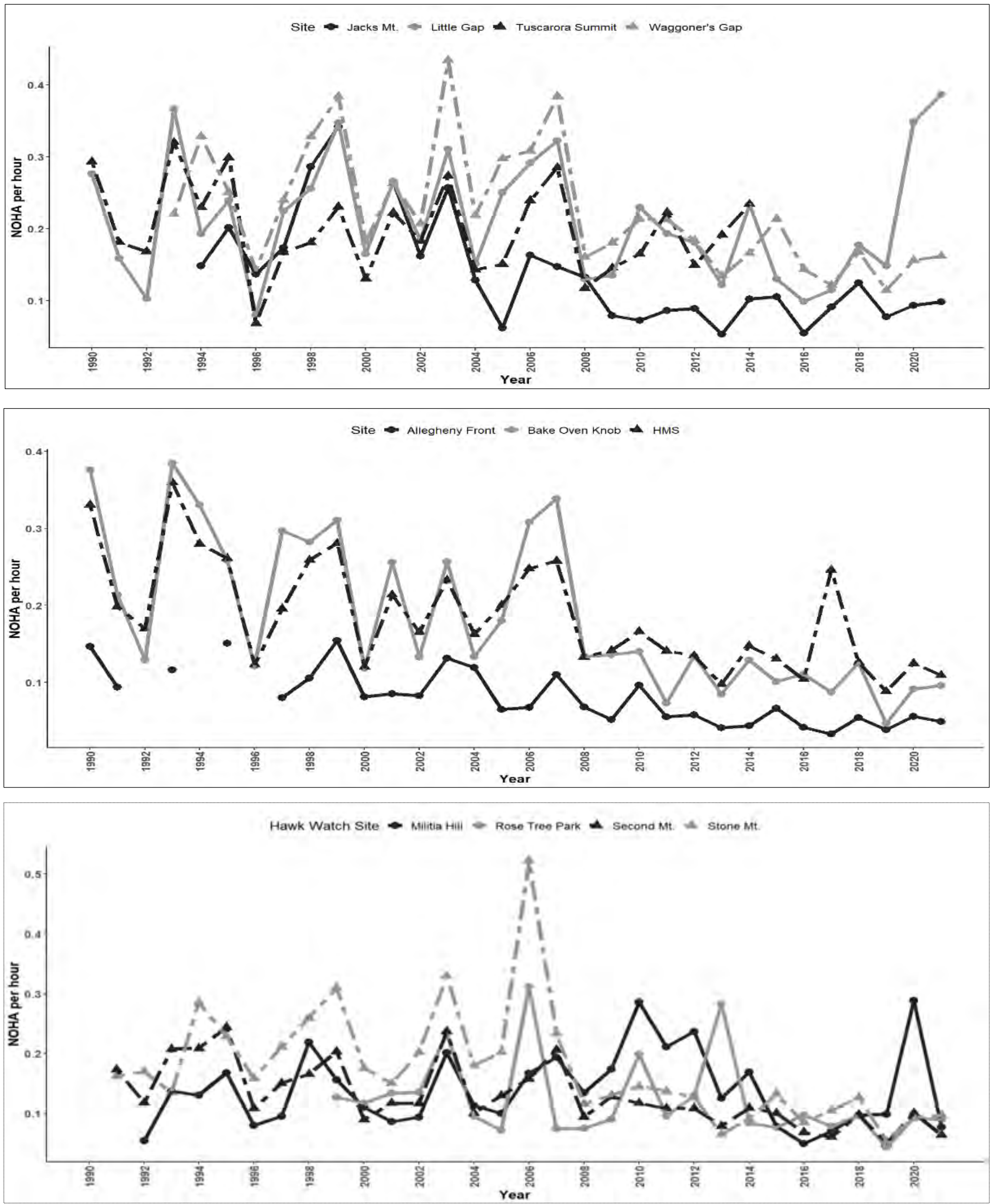

Fig. 2. Total annual harrier sightings at 11 Pennsylvania hawk watches from 1990 to 2020. Data adjusted by effort by dividing total harrier sightings by total observer hours. Figure created in R version 3.6.0 (R Core Team 2019) using ggplot2 and patchwork programs (Wickham 2016, Pedersen 2020).

If harriers are migrating shorter distances, it is possible more recent migration and winter samples in Pennsylvania may not be showing population cycles even though they could be occurring. Further analyses of Christmas Bird Counts or migrating immatures from more northern watch sites, such as in New England or the Great Lakes states, may show a stronger pattern of peaks in immatures at hawk watches and on the CBC.

Our results did not support the prediction that counts of wintering juvenile harriers would be higher in peak years in the WRS. This analysis should be repeated in a state with a larger harrier population to limit the influence of a low sample size.

Northern Harrier productivity and behavior has been linked to meadow vole populations across North America (Hamerstrom et al. 1985, Simmons et al. 1986). However, it is difficult to unequivocally connect productivity and behavior on breeding grounds to the peaks of migrating harriers. However, prey-dependent cycles are frequently observed in raptors. A prey-dependent migration cycle occurs in Northern Saw-whet Owls (*Aegolius acadicus*), with irruptions corresponding to higher immature populations in years of high prey populations (Confer et al. 2014). Fluctuations in prey populations also drive irruptions of Snowy Owls (*Bubo scandiacus*) and Boreal Owls (*Aegolius funereus*) (Cheveau et al. 2004, Robillard et al. 2016). More research is needed to determine if increased fecundity in harriers is contributing to the cycle observed at major hawk watches.

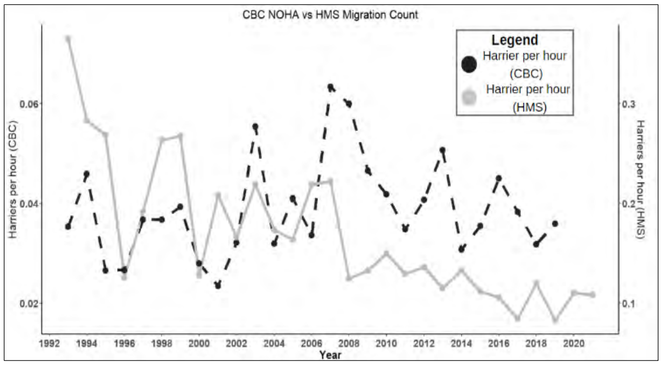

Fig. 3. Total harriers per hour during CBC compared to annual migration count at Hawk Mountain Sanctuary (HMS). Both projects had significant autocorrelations at a four-year lag. CBC count comes from the sum of harriers sighted divided by total observer effort across the state. Annual migration counts were calculated by dividing the total number of harriers observed per year by the total observer effort. Figure created in R version 3.6.0 (R Core Team 2019).

In summary, Northern Harrier migration and early season wintering data suggest there is evidence of four-year population cycles at three PA hawk watches and a three-year cycle at two hawk watches. However, this cycle has decreased since 2008 which may mean population declines or short-stopping is influencing migration patterns observed. These findings emphasize the need for more research as well as conservation steps to protect this iconic grassland raptor and to ensure its continued presence as a migrating and wintering bird of Pennsylvania.

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