Factors influencing occupancy, success, and nestling growth at American Kestrel (*Falco sparverius*) nest boxes in the Upper Midwest

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Project background:

The American Kestrel (*Falco sparverius*) is a widespread but declining raptor species. Trends from migration sites and annual bird counts track kestrel declines as beginning in the 1960s, and decades of research have not succeeded in illuminating the primary causes of kestrel population decline throughout their range. Kestrels are likely experiencing different threats at local scales. One potential threat is loss of nesting habitat. Regardless of widespread nest box programs to increase habitat, kestrel productivity in the Upper Midwest has not been extensively studied. Collecting data on drivers behind nest use and success locally is stated as a priority for future kestrel research and is critical for the implementation of kestrel conservation plans (Smallwood et al. 2009, Sauer et al. 2013, McClure et al. 2017, Ruegg et al. 2021). We sought to learn about differences in occupancy, productivity, and nestling growth at kestrel nest boxes in Minnesota and Wisconsin that may be used to influence future management and conservation practices for this declining species.

In this study we used methods of nest box monitoring, geospatial habitat analysis, and stable isotope analysis to identify differences in nest box occupancy, success, and nestling growth and survival in kestrel nest box programs in Minnesota and Wisconsin. We developed growth curves for kestrel nestlings in our study area, and we modeled relative diet and habitat impacts on these growth curves. We have not found another study using this combination of methods to assess a large regional kestrel population spanning a range of complex habitats.

Objectives:

1. Determine if land cover impacts nest box occupancy, success, or nestling growth for American Kestrels
2. Understand the role (if any) that diet quality (measured by trophic position) plays in nestling growth of American Kestrels

Methods:

We conducted this study at opportunistic locations where kestrel nest box programs had already been established and at locations lacking nest boxes with the purpose of establishing a new site for monitoring. The study area consisted of seven sites in Minnesota and Wisconsin, each containing between 13 and 199 boxes for a total of 434 boxes in 2022 and 412 boxes in 2023 (Table 1, Figure 1). Because of the opportunistic nature of our study, the nest boxes varied in mounting surface and number of years active (1-24; mean = 7.46 years), but all boxes were constructed and placed for the purpose of attracting nesting American Kestrels. Data from nest boxes were contributed by the following organizations: Friends of Sax-Zim Bog, the MN DNR Nongame Wildlife Program and Minnesota Army National Guard AHATS (Arden Hills Army Training Site), Beaver Creek Nature Center, Central Wisconsin Kestrel Research, Madison Audubon Society (now – Badgerland Bird Alliance), and Cedar Grove Ornithological Research Station.

Table 1. Number and state location of American Kestrel nest boxes monitored per site. The sample size of nest boxes varied between the two years of our study and varied greatly across sites.

Site	Nest boxes - 2022	Nest boxes - 2023	State
Arden Hills Army Training Site (AHATS)	15	15	Minnesota
Beaver Creek Reserve	13	13	Wisconsin
Central WI Kestrel Research	52	52	Wisconsin
Cedar Grove Ornithological Research Station (CGORS)	30	31	Wisconsin
Douglas Co.	75	74	Wisconsin
Friends of Sax-Zim Bog (FOSZB)	50	50	Minnesota
Madison Audubon Society (MAS)	199	177	Wisconsin
Total	**434**	**412**	

Nest boxes were monitored multiple times per breeding season with a pole-mounted camera. Circular buffers were developed at different spatial scales (100 m, 500 m, 1 km, and 2 km radii) in order to summarize the land cover type surrounding each nest box in ArcGIS Pro (V 3.1.1). Land cover data was obtained from the National Land Cover Database (NLCD) in 30 m resolution raster format (https://www.mrlc.gov/). We combined land cover types that were similar and renamed others for our purposes: developed open + low intensity development + medium intensity development + high intensity development = "developed"; herbaceous grasslands + herbaceous wetlands = "natural open"; pasture/hay; cultivated crops = "crop". The relative proportion of each land cover type in each buffer size was obtained and used as predictor variables. Clutch initiation date (CID), or the date when the first egg in a clutch is laid, and number of visits to a nest are other commonly used covariates to nest success. Since we usually waited at least seven days between nest checks, we almost never observed the date of clutch initiation. We instead calculated CID with the following equation:

$$CID = banding\ date - (age\ of\ oldest\ nestling + 30 + (2 * number\ of\ eggs\ laid))$$

We derived this equation as kestrels have been known to lay one egg every 1-3 days and incubate eggs for 30 days on average in the wild (Smallwood and Bird 2020).

Growth rate over time of nestling birds can be an effective measure of productivity, but it requires at least two measurements at different times from each individual (Ricklefs 1968). We wanted to avoid handling the nestlings in our study more than once to limit stress and reduce the workload requested of volunteers. Kestrel nestlings were removed from their nest boxes between 11-31 days of age (mean = 19.76 days) to be fit with a U.S. Geological Survey (U.S.G.S) aluminum band and for morphological data to be recorded. Nestlings were aged following descriptions in a commonly used aging guide (Klucsarits and Rusbuldt 2007). After data collection, nestlings were promptly placed back in their nest boxes. We developed one logistic growth curve each for males and females using one-time mass measurements of each nestling in both 2022 and 2023 combined. Because of our large sample size of mass data from nestlings of a wide age range (11-31 days, mean = 19.6 days), we feel confident that our growth curves perform as well as traditional curves with multiple measures over time. The aggregate growth curve was used as an expected growth curve from which we used the residual values as a metric of growth for each nestling. Negative residuals indicated slower than expected relative growth whilst positive residuals indicated faster than expected relative growth in our study population.

From each nestling, we collected 3-4 breast feathers at the time of banding. Feathers from 1-3 nestlings from each eligible nest box were sent for stable isotope analysis. This method was chosen because stable isotopes provide a record of the diet of a bird while the feather was growing rather than at one point in time such as with cloacal swabbing (Inger and Bearhop 2008). Thus, we can assume that stable isotope results from kestrel chicks in our study reflect enrichment from their diet during feather growth in our nest boxes. Isotope ratios are reported in the delta notation δX‰ relative to international standards, Vee PeeDee Belemnite (VPDB) and Air for carbon and nitrogen, respectively, where:

$$\delta X = \left(\frac{R_{sample}}{R_{standard}} - 1\right) * 1000$$

δX refers to the ratio of the heavy to light isotope for C or N. $\delta^{15}N$ can be used as a proxy for relative trophic level with higher $\delta^{15}N$ values indicating an organism is eating at a higher trophic level (Herrera et al. 2003). $\delta^{13}C$ in tissues can be used to infer the vegetation present where an organism is feeding in a terrestrial system because C_4 plants are enriched in $\delta^{13}C$ relative to C_3 plants (Smith and Epstein 1971, Hobson 1999). For kestrels, $\delta^{13}C$ values in feathers may indicate if they are hunting primarily in agricultural areas or uncultivated grasslands depending on the specific flora present. We included $\delta^{13}C$ as a covariate to supplement our data on nestling growth in cropland as well as for its ease of analysis along with $\delta^{15}N$. We tested the relationship between nestling growth and diet by regressing growth index on $\delta^{15}N$ and $\delta^{13}C$ values as predictor variables. We sampled grasshoppers and dominant plants opportunistically from each of our seven nest box sites and analyzed them for $\delta^{15}N$ and $\delta^{13}C$, respectively, to control for potential baseline-driven shifts in isotopic enrichment in our feather samples related to gross environmental variation across our sites (Post 2002). Feather and baseline sample analysis were conducted by the Central Appalachians Stable Isotope Facility (CASIF) and the University of Windsor Great Lakes Institute for Environmental Research (GLIER) Stable Isotopes Lab.

All model analyses were performed in the R statistical environment (V 2023.06.2+562; R Core Development Team 2023). We used generalized linear models (*stats* package; R Core Development Team 2023) with a binomial distribution and logit link function to assess predictor variable impacts on nest box occupancy and success. Nest success was evaluated as a binary metric as well as a proportion of number of eggs hatched per total eggs per box. For nestling growth, we used linear mixed models (*lme4* package; Bates et. al 2015) with nest box by year (2022 or 2023) as a random effect.

Results:

Of the 433 nest boxes available in 2022, 210 (48.39%) were occupied. In 2023, 203/412 nest boxes were occupied (49.27%). Nest box occupancy decreased with increasing proportions of cropland and developed land and increased with increased proportions of pasture/hay. There was no relationship between occupancy and proportion of natural open land (Figure 2).

The mean clutch size in our study was 4.79 ± 0.06 (95% CI) eggs. An average of 3.68 ± 0.17 (95% CI) eggs hatched per nest. Clutch initiation date (CID) was negatively correlated with both overall nest success and egg hatching proportion, indicating that fewer nests succeeded and fewer eggs hatched the later in the season a nest began. Fewer eggs hatched as proportion of pasture/hay increased, but more eggs hatched as proportions of natural open land and cropland increased (Figure 2).

We collected data from 1,502 nestling kestrels during the two breeding seasons of our study. Nestlings with incomplete morphological data (age, mass, sex) were removed from our analysis, as these characteristics were necessary for fitting the logistic growth curves. This resulted in data from 1,345 nestling kestrels (656 females, 689 males) aged 11.5-31 days available for growth modeling. Nestling growth residuals were lower as CID increased, and residuals were higher as proportion of cropland increased (Figure 2). Nestling growth was unrelated to baseline-corrected $\delta^{13}C$ and $\delta^{15}N$ in feathers based on our analysis.

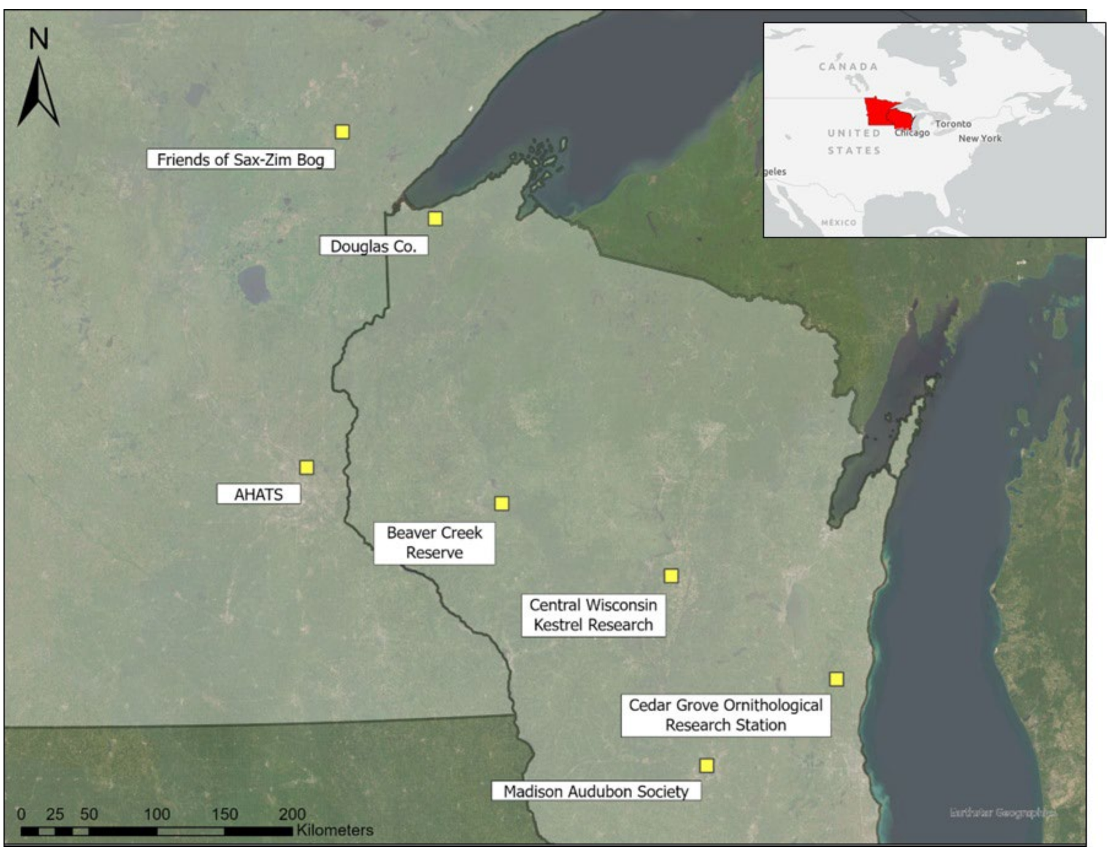

Figure 1. American Kestrel nest box sites. Yellow boxes show the approximate location of each site and list the name of the collaborating organization. See Table 1 for sample size of nest boxes at each site.

A
B
C

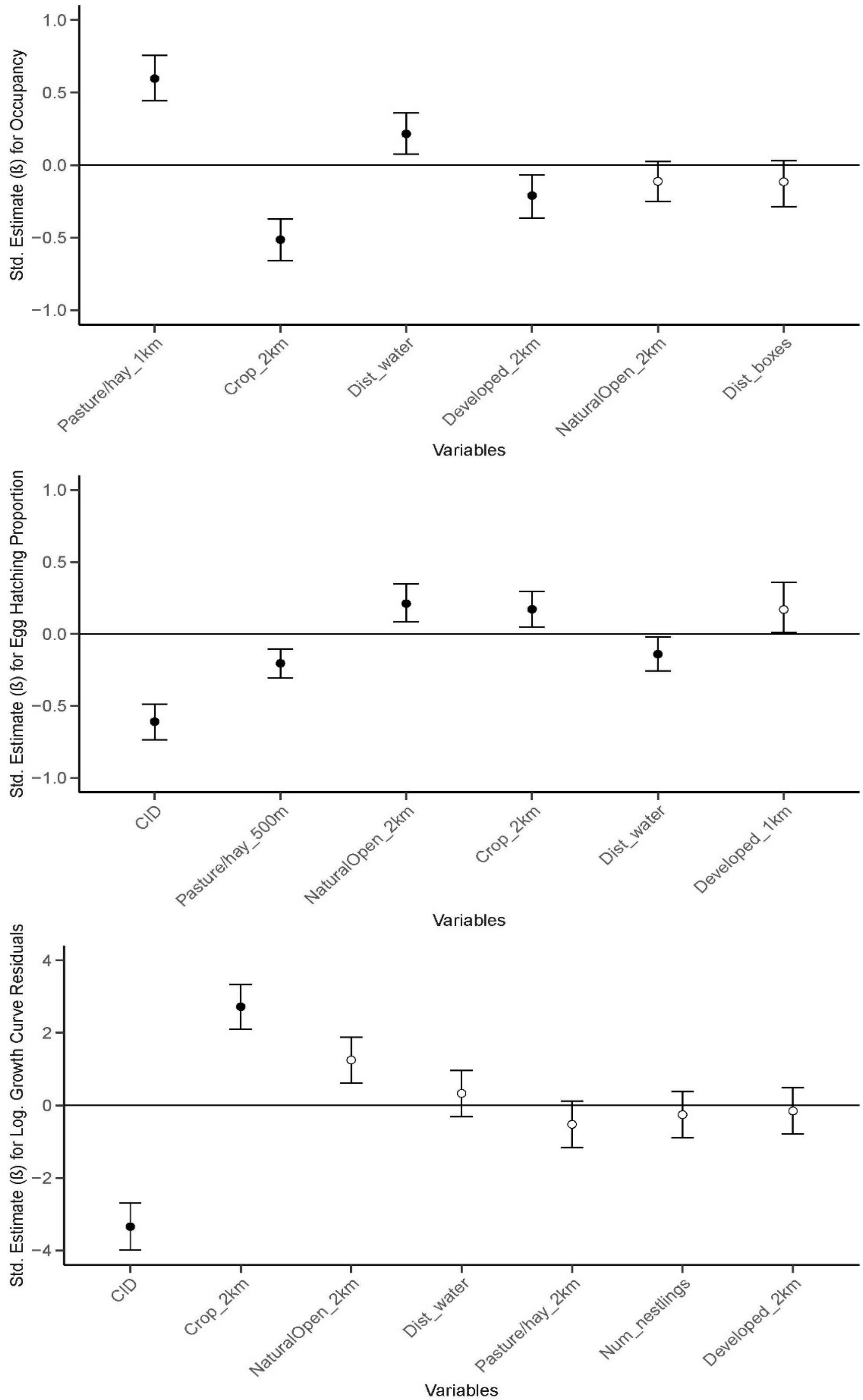

Figure 2. Standardized coefficient (β) values of univariate models predicting nest box occupancy (A), egg hatching proportion (B), and nestling growth residuals (C). Variables for land cover only included at best-performing scale of 100 m, 500 m, 1 km, and 2 km radii. Black circles denote significant ($p < 0.05$) models, and white circles denote non-significant ($p \geq 0.05$) models. Error bars reflect 95% CI.

Discussion

Our nest box occupancy and success rates are similar to what is expected at American Kestrel nest box sites. Surprisingly, occupancy was greater as pasture/hay proportions increased, but the opposite effect was found as cropland increased. This may be because a dominant crop in our study area is corn, which can be higher than the vegetation that kestrels typically prefer for nesting and foraging (Smallwood and Bird 2020). We also found that kestrels didn't nest as frequently near larger proportions of developed land, as expected, likely due to disturbance.

We found high overall nest success (~85%) at our boxes, but both nest success and egg hatching proportion significantly decreased the later a nest was started. This may be because older kestrel adults nest earlier and have more experience in raising young (Snyder and Smallwood 2022). We also found that more eggs hatched as proportions of cropland and natural open land increased. This suggests that environmental conditions may also influence the decision or ability of kestrel adults to lay viable or hatchable eggs.

CID was the most important variable for predicting nestling growth in our study, and later nests were more likely to have slower-growing nestlings. This may reflect prey availability or the age of the parents (Snyder and Smallwood 2022). For land cover, cropland resulted in faster nestling growth in our study, similar to our results on egg hatching proportion. This may indicate that kestrels in our study region are adapted to living near high amounts of agriculture and are able to thrive in conditions that have been previously considered detrimental to kestrel success. This underscores the importance of incentivizing farmers to reduce pesticide and rodenticide use in place of using kestrels as natural pest deterrent which has been proven effective in some studies (Shave and Lindell 2017).

Surprisingly, we found virtually no correlation between trophic level (baseline-corrected $\delta^{15}N$) of kestrel nestlings and growth speed. This contradicts results from past studies which found positive relationships between trophic position or prey type and body condition (Fairhurst et al. 2014, Ronconi et al. 2014, Resano-Mayor et al. 2016). We believe this may be because diet quantity is more important for nestling growth or because kestrel parents are only bringing the highest-quality prey to their young. Regardless of the reason, we suggest that future studies focus on diet quantity, not quality, as it relates to land cover in American Kestrels.

Budget Report:

Complete funding for this project was supplied by grants from the Minnesota Ornthologists' Union Savaloja Grant Program, the Duluth Superior Community Area Fund (DSCAF), Madison Audubon Society (now – Badgerlind Bird Alliance), and from private donations. The entire MOU Savaloja grant was used for stable isotope analysis of nestling feather samples in early 2023.

Item	Initial Budget Amount	Actual Cost	Funding Sources
GoPro Hero8 Black	299.99	299.99	Hawk Ridge Bird Observatory
C and N isotope analysis	18,500.00	15,491.96	MOU, DSCAF, private donations
iButton temperature loggers and mounting clips	614.25	1024	Hawk Ridge Bird Observatory, Madison Audubon Society (now – Badgerland Bird Alliancce)
Total Costs		**16,815.95**	

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