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Turkey Vulture survival is reduced in areas of greater road density

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ABSTRACT

The demography of, and factors that influence these metrics, are largely unknown for most vultures in the Americas. Survivorship of Turkey Vultures (*Cathartes aura*) may be influenced by landscape heterogeneity and human disturbance. We quantified the effects of landscape composition (Shannon's diversity index) and configuration (contagion, edge density, and largest patch index), and human disturbance (road density) on the annual and seasonal survival probabilities of the three North American breeding populations (western, central, and eastern) of Turkey Vultures that spend the nonbreeding season in the southeastern portion of the Nearctic and the northern Neotropics during a 17-year period. We used Cox's proportional hazards models with time-varying covariates to estimate spatial and temporal changes in survival rates of adult Turkey Vultures. Road density, but not landscape composition or configuration, influenced survival rates in space and time. Overall annual survival averaged 0.87 (95% confidence interval [CI]: 0.74–0.98). Mortality risk was low in western and central populations (hazard ratio < 1) but was 3.7 times greater for vultures in the eastern population. Survival during the breeding (0.97, 95% CI: 0.96–0.98) and outbound migration (1.0, 95% CI: 1–1) seasons was significantly higher than the other seasons. Average survival tended to be higher for nonbreeding (0.81, 95% CI: 0.71–0.88) compared to return migration (0.69, 95% CI: 0.56–0.81) seasons. The risk of mortality for all vulture populations increased with road density, and this was greater during the nonbreeding and return migration seasons. The spatial variation in road density across the Americas may generate a network of ecological traps for Turkey Vultures induced to stop in areas of greater road-kill abundance. Road-killed animals acting as an attractant for vultures can increase the occurrence of vulture–vehicle collisions and potentially aggravate human–wildlife conflicts. Further analyses are needed to address survivorship and mortality factors for young birds. Our results may help the implementation of specific mitigation efforts to reduce human–vulture conflicts and vulture mortality. For instance, concentrating efforts to remove road-killed animals in areas where road density is highest can likely reduce vulture–vehicle collisions and associated mortalities of these birds.

Keywords: demography, ecological trap, landscape composition, landscape configuration, road density, scavengers, survival

How to Cite

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LAY SUMMARY

- Prior to this study, the factors affecting the survival of Turkey Vultures in the Americas were practically unknown. We combined Turkey Vulture movement data with updated geographic information layers to model annual and seasonal survival as a function of environmental covariates within a 17-year period.
- Overall average survival was high (>75%), but mortality risk increased with road density. Mortality risk was greater during the nonbreeding and return migration seasons.
- The road networks across the Americas appears to create ecological traps for Turkey Vultures where road densities are high and can increase the occurrence of vulture–vehicle collisions and potentially aggravate human–wildlife conflicts.
- Additional research may be warranted regarding the impact of other linear infrastructures, such as railways and powerlines, and the management of human–vulture conflict on long-term survival of Turkey Vultures.
- In regions characterized by greater road density increased efforts of road-kill removal may reduce vulture–vehicle collisions and overall vulture mortality.

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La supervivencia de *Cathartes aura* se reduce en áreas de mayor densidad de carreteras

RESUMEN

La demografía y los factores que influyen en estas métricas son en su mayoría desconocidos para la mayoría de los buitres en las Américas. La supervivencia de la Cataneja (*Cathartes aura*) puede verse influenciada por la heterogeneidad del paisaje y la perturbación humana. Cuantificamos los efectos de la composición (índice de diversidad de Shannon) y configuración (contagio, densidad de bordes e índice de parche más grande) del paisaje, así como de las perturbaciones humanas (densidad de carreteras), en las probabilidades de supervivencia anual y estacional de las tres poblaciones reproductivas de América del Norte (oeste, centro y este), que pasan la temporada no reproductiva en la porción sureste del Neártico y en el norte de la región Neotropical, durante un período de 17 años. Utilizamos modelos de riesgos proporcionales de Cox, con covariables que variaron en el tiempo, para estimar los cambios espaciales y temporales en las tasas de supervivencia de los adultos de *C. aura*. La densidad de carreteras, pero no la composición o configuración del paisaje, influyó en las tasas de supervivencia en el espacio y el tiempo. La supervivencia anual promedió 0.87 (IC del 95%: 0.74–0.98). El riesgo de mortalidad fue bajo en las poblaciones del oeste y centro (cociente de riesgo < 1), pero fue 3.7 veces mayor para los buitres en la población del este. La supervivencia durante la temporada reproductiva (0.97, IC del 95%: 0.96–0.98) y la temporada de migración de otoño (1.0, IC del 95%: 1–1) fue significativamente mayor que en las demás temporadas. La supervivencia promedio tendió a ser más alta durante la temporada no reproductiva (0.81, IC del 95%: 0.71–0.88) en comparación con la temporada de migración de primavera(0.69, IC del 95%: 0.56–0.81). El riesgo de mortalidad para todas las poblaciones de catanejas aumentó con la densidad de carreteras, y esto fue mayor durante la temporada no reproductiva y la temporada de migración de primavera. La variación espacial en la densidad de carreteras en las Américas puede generar una red de trampas ecológicas para los individuos de *C. aura* que se ven inducidos a detenerse en áreas de mayor abundancia de animales atropellados. Los animales atropellados que actúan como atrayentes para los buitres pueden aumentar la ocurrencia de colisiones entre buitres y vehículos y potencialmente agravar los conflictos entre los humanos y la vida silvestre. Se necesitan análisis adicionales para abordar los factores de supervivencia y mortalidad en aves jóvenes. Nuestros resultados pueden ayudar en la implementación de esfuerzos de mitigación específicos para reducir los conflictos entre humanos y buitres, y la mortalidad de los buitres. Por ejemplo, concentrar los esfuerzos en remover animales atropellados en áreas donde la densidad de carreteras es más alta probablemente reducirá las colisiones entre buitres y vehículos y las mortalidades asociadas de estas aves.

Palabras clave: carroñeros, composición del paisaje, configuración del paisaje, demografía, densidad de carreteras, supervivencia, trampa ecológica

INTRODUCTION

Mortality is a key regulatory mechanism of animal populations. Understanding the processes influencing mortality and survival is foremost to addressing basic questions in ecology and conservation (Skalski et al. 2010, Murray and Sandercock 2020). Further, information on the environmental drivers of survival and mortality are key components of management and conservation interventions (Murray 2006). For instance, species can often be controlled by reducing their survival through focused management of the ecosystems in which they live (Lambert et al. 2008), or enhanced for organisms with high juvenile mortality, if they are head-started and released once survival probabilities are known to be higher (Poessel et al. 2011).

Despite the importance of quantifying life-history traits for wildlife conservation, survival is poorly understood in birds of prey, particularly in vultures (Newton 1979, Newton et al. 2016). Globally, vulture mortality events have included intentional poisoning, incidental ingestion of lead ammunition, and other human activities (Forman and Alexander 1998, Ogada et al. 2012, Ives et al. 2022). Furthermore, vultures move long distances across varied landscapes searching for food, highlighting the need to better understand their patterns of survival in human-dominated landscapes.

Previous studies have reported on the inverse relationship between cumulative human disturbance (i.e., human footprint) and the annual survival of vultures (Coleman 1985, Arrondo et al. 2020). However, the effects of landscape composition and configuration on vulture demography are poorly understood. The effect of landscape composition and configuration on species persistence varies across different groups of birds (Uezu and Metzger 2011). For some avian species, apparent survival shows an ambivalent relationship with landscape composition, characterized by the number of land cover classes and the proportion of these (Seckinger et al. 2008, Robinson et al. 2018). Survival can be negatively influenced by landscape configuration represented in the aggregation of specific land cover types and edge density (Schmitz and Clark 1999, Seckinger et al. 2008, Briggs et al. 2011, Peak and Thompson 2014).

The factors that affect the survival of vultures in the Western Hemisphere are practically unknown, with a limited number (5) of published studies reporting survival estimates for four of the seven Cathartiformes species. Of these, no published information is available on the influence of human disturbance or landscape composition and configuration (Stewart 1977, Coleman 1985, Temple and Wallace 1989, Meretsky et al. 2000, Blackwell et al. 2007). Our goal in this study is to fill information gaps on the demography of vultures in the Western Hemisphere using the Turkey Vulture (*Cathartes aura*) as a model species.

Turkey Vultures are the most widely distributed vulture in the Western Hemisphere where they inhabit human-dominated landscapes (Kirk and Mossman 2020). The annual survival probability of the Turkey Vulture has been reported for the northeastern portion of this species' range (0.75–0.78, Stewart 1977, Coleman 1985). However, variation in survival during the breeding, nonbreeding, and migration seasons has yet to be determined for different populations.

Here, we estimated seasonal and annual survival probabilities of the three North American populations (western, central, and eastern) of the Turkey Vulture that spend the nonbreeding season in the southeastern portion of the Nearctic and the northern Neotropics. Furthermore, we examined how survival was influenced by human disturbance, and landscape composition and configuration during a 17-year period. We predicted Turkey Vulture populations occupying landscapes with greater human disturbance (e.g., greater human population and/or road densities) would exhibit reduced survival. Similarly, we predicted survival probability would be lower in heterogenous landscapes, or landscapes with greater land cover richness, diversity and edge density, and lesser contagion (a measure of landscape aggregation and interspersion) and aggregation.

METHODS

Study Area

The Americas are a physiographically and biologically diverse continent encompassing two major biogeographic regions of the globe, the Nearctic and Neotropical realms (Brown and Lomolino 1998). The Nearctic region occupies 20,591,272 km^2 and includes 29 biogeographic provinces. The Neotropical region includes 57 biogeographic provinces across 19,206,336 km^2 (Escalante et al. 2021, Morrone et al. 2022). The geographic extent of our study includes most of the Nearctic and northern Neotropical regions, specifically an area located from the Equator to the 56th North parallel (Figure 1). The large geographic region covered by our study includes a wide diversity of climates and weather. At least 25 separate climate types have been described for the Nearctic and 18 for the Neotropical realms (Beck et al. 2018).

We selected the Terra and Aqua combined Moderate Resolution Imaging Spectroradiometer Land cover type product (MODIS-MCD12Q1, Friedl and Sulla-Menashe 2019) to describe land use and land cover (LULC) within our study area and for subsequent analyses. This database provides global land cover information at yearly intervals with 500-m spatial resolution. The LULC within the geographic extent of this work includes 17 classes of which grasslands, savannas, and woody savannas are the dominant land cover types.

Turkey Vulture Data Collection

Between 2003 and 2021, a total of 84 Turkey Vultures of three different subspecies were trapped by Hawk Mountain Sanctuary and the U.S. Department of Agriculture in Canada (Saskatchewan) and the United States (Arizona, California, Florida, Minnesota, Pennsylvania, South Carolina). Turkey Vultures were trapped using walk-in traps, padded-leghold traps or monofilament noose traps. Trapped birds were tagged with patagial tags and equipped with satellite transmitters as authorized by U.S. Federal Bird Banding Permits No. 22749 and 06859 and Canadian Bird Banding Permit No. 00460. Satellite transmitters were attached using a backpack design with 11-mm Teflon ribbon (Bally Ribbon Mills, Bally, Pennsylvania, USA). Units deployed on Turkey Vultures included Solar Argos/GPS PTT (Microwave Telemetry, Inc., Columbia, Maryland, USA) and Argos/GPS PTT (North Star Science and Technology, Oakton, Virginia, USA). The weight of PTT units ranged from 30 to 70 g.

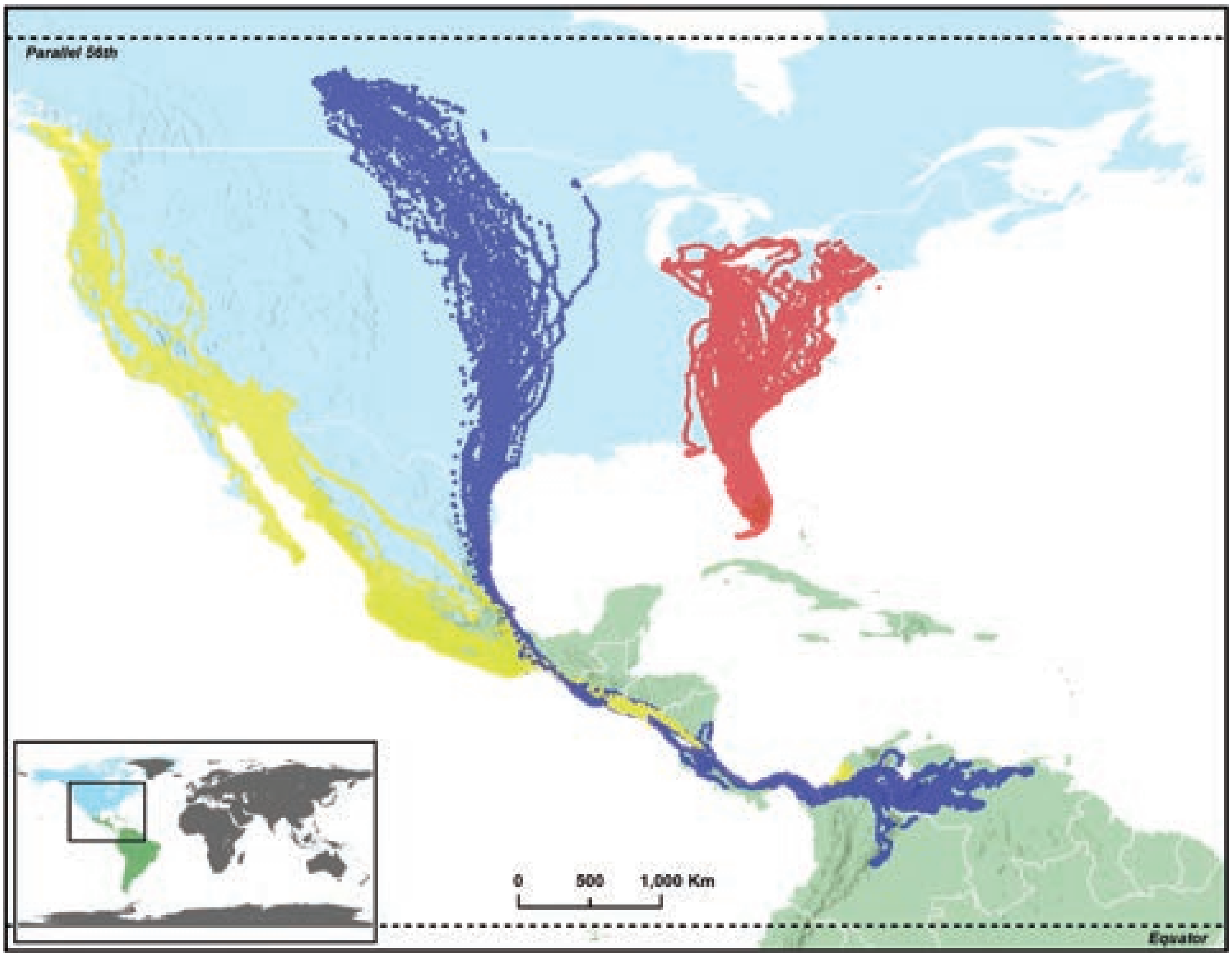

FIGURE 1. Geographic extent of the study area and trapping locations of Turkey Vultures (*Cathartes aura*) included in the analysis. Light blue and green colors represent the Nearctic and Neotropical realms, respectively. Yellow dots = vultures from western population, blue dots = vultures from central population, red dots = vultures from eastern population.

TABLE 1. Effects of road density and landscape features on annual and seasonal survival of North American Turkey Vultures (*Cathartes aura*) between 2003 and 2019.

Models for annual survival	K	AIC_c	ΔAIC_c	ModelLik	w_i
Road density	1	54.7	0.0	1.0	0.7
Landscape composition	1	57.5	2.8	0.2	0.2
Landscape configuration	3	59.5	4.8	0.1	0.1
Models for seasonal survival					
Season:Road density	4	59.9	0.0	1.0	0.8
Season:Landscape composition	4	63.3	3.4	0.2	0.2
Season:Landscape configuration	12	71.7	11.7	0.0	0.0

K = number of model parameters, ΔAIC_c = difference between AIC_c values from the competitive and top model, w_i = AIC_c model weight, ModelLik = relative likelihood of the model. Landscape composition = Shannon's Diversity Index. Landscape configuration = Contagion, + Edge density + Largest patch index. Season = Breeding | Outbound migration | Nonbreeding | Return migration.

Units were programmed with four different duty cycles (1 fix 3 hr^{-1}, 1 fix hr^{-1} between 05:00 and 10:00, fix hr^{-1} between 05:00 and 22:00, 1 fix hr^{-1}) based on research needs at the beginning of each project.

For our study, we selected only individual Turkey Vultures that exhibited migratory behavior. We followed Turkey Vultures' seasonal classification as defined by Dodge et al. (2014), including breeding (after return migration and before outbound migration), outbound migration ([post-breeding migration], movement trajectories with North–South directionality after the breeding season and before nonbreeding season), nonbreeding (after outbound migration and before return migration), and return migration ([pre-breeding migration], movement trajectories with South–North directionality after nonbreeding season and before breeding season). We used Migration Mapper 2.0 (Merkle et al. 2022) to identify, by analyzing net-squared displacement plots, breakpoints in movement trajectories that allowed annotating the starting and ending date of each season.

The final dataset included 53 adult individuals from three different subspecies tracked during 2003 and 2019. We focused our work on the geographic distribution of these subspecies rather than taxonomic differences. Thus, the western population includes 28 individuals of the subspecies *C. a. aura* and *C. a. meridionalis*; 12 individuals of *C. a. meridionalis* in the central population, and 13 in the eastern population belonging to *C. a. septentrionalis*.

Environmental Variables

We selected publicly available environmental variables from GIS data for each year between 2003 and 2019. We used nighttime light data (ntl, nanowatts per centimeter squared per steradian), human population density (human, people km^{-2}), and primary and secondary road density (road, m km^{-2}) as a proxy of human disturbance. Nighttime light and human population density were available in raster format at 500-m and 1,000-m spatial resolution, respectively (Chen et al. 2021, Rose et al. 2021). We used vector data from the global roads open access data set (CIENSIN and ITOS 2013) to generate raster files of road density using the *Spatial Analyst Tools* in ArcGIS 10.3 (ESRI 2011). Furthermore, we calculated the line density in each pixel using a search radius of 1,000 m.

We used land cover data (500-m grain size) from Terra MODIS MCD12Q1 (Friedl and Sulla-Menashe 2019) to obtain landscape composition and configuration metrics for each year. Landscape metrics were calculated using Fragstat 4.2 (McGarigal and Marks 1995) with the 8-neighbor rule and a circular moving window with a 2,500-m radius (19.6 km^2). Further, we created a spatially explicit raster for each metric at the landscape level. Landscape composition metrics included the total number of land cover types or patch richness (pr) and Shannon's Diversity Index (shdi), whereas configuration metrics included number of patches (np), patch density (pd, number of patches 100 ha^{-1}), largest patch index (lpi, percentage), edge density (ed, m ha^{-1}), and contagion (contag, percentage) (Turner and Gardner 2015). All rasters were snapped and resampled to 1,000-m spatial resolution.

Survival Analysis

To estimate the annual and seasonal (breeding, nonbreeding, outbound migration, and return migration seasons) survival of North American Turkey Vultures, we used the extended Cox Proportional Hazard model, which allows incorporating time-varying covariates into model estimates (Therneau and Grambsch 2000). The origin or starting point of the survival time estimate was the first day the individual bird entered into the at-risk condition, and the event of interest was the verified mortality of the individual vulture. We considered vultures alive from the day of release (point of entry in the survival time estimate; first GPS fix in the dataset) until the day before telemetry data indicated no further movement. All vultures whose transmitter stopped working before the event of interest (fates unknown) were right-censored.

We built monthly live and dead encounter histories for all vultures included in the analysis by randomly selecting 1 GPS fix at the end of the month and the first fix on the day of the event. We associated each of these fixes with the corresponding human disturbance and landscape metrics covariates. Specifically, the covariate value within an area of ≤ 19.6 km^2 (radius of 2,500 m, equivalent to three times grain size) at location i during time t.

We estimated annual and seasonal survival by fitting two univariate models. The model for annual survival included "population" as main effect, whereas the model for seasonal survival included the interaction between "populations" and "seasons." We calculated and reported accordingly average, standard errors (SE) or 95% nonparametric bootstrap confidence intervals (95% CI) of tracking time and survival estimates. Furthermore, we constructed two additional sets of models, each set included three models (one for each

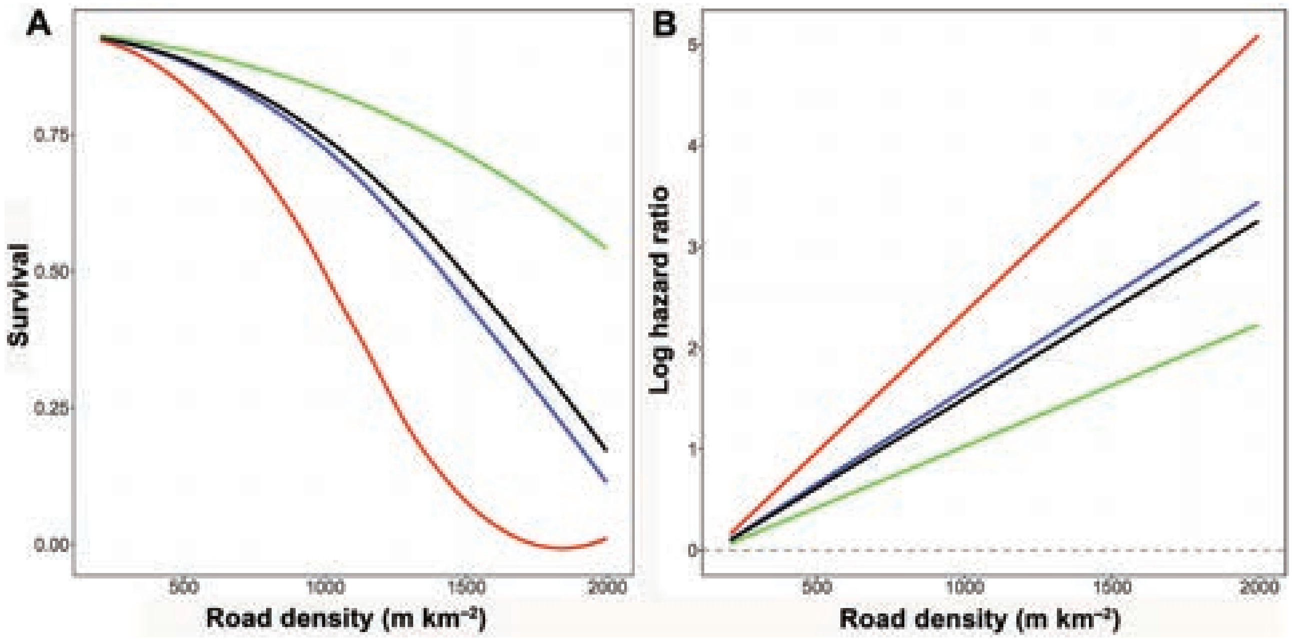

FIGURE 2. Effect of road density on the survival probability (**A**) and risk mortality (log hazard ratios, (**B**) of North American Turkey Vultures (*Cathartes aura*) between 2003 and 2019. Green line = breeding season, blue line = Nonbreeding season, black line = outbound migration, and red line = return migration. Log hazard ratios greater than zero indicate higher mortality risk and lower survival probability. Shadow areas correspond to the standard error.

hypothesis), to assess potential influence of human disturbance (ntl, human, road), landscape composition (pr, shdi), and landscape configuration (np, pd, lpi, ed, contag) on annual and seasonal survival of vultures (Table 1). All covariates were standardized by subtracting the mean and dividing by the standard deviation (x-μ/σ) prior to analysis and checked for multicollinearity using the variance inflation factor (VIF) metric (Zuur et al., 2010). All variables with VIF > 3 were removed from the models. Excluded variables included ntl, pr, np, and pd. Due to convergence issues, the variable human population density (human) was removed from the final human disturbance models. We used second-order Akaike's Information Criterion (AIC_c) and AIC_c weights (w_i) to select the top-ranked model(s) ($\Delta AIC_c < 2$) for inference.

We tested the assumption of proportional hazard for the top-ranked model(s) by plotting parameter coefficients over time and a score test for a slope of "0" (Therneau 2021), a significant deviation from the proportional hazard assumption ($P < 0.05$) or a non-zero slope over time indicating lack of proportionality and occurrence of time-varying covariates (Zhang et al. 2018). Analyses were conducted using package *survival* and *car* in the R statistical software (Fox and Weisberg 2019, R Core Team 2018, Therneau 2021).

RESULTS

Fifty-three North American Turkey Vultures were tracked for an average of 1007 ± 118 days. Of these, 17 were right-censored, and eight were verified mortalities. Six mortalities (46.2%) were vultures from the eastern population, and the other two birds were from central (8.3%) and western (3.6%) populations. Mortalities were reported by Hawk Mountain Sanctuary and U.S. Department of Agriculture-Wildlife Services personnel that recovered the carcasses. Mortalities occurred between 2014 and 2019, one mortality (1.8%) occurred during the breeding season, two (3.7%) during return migration, and five (9.4%) occurred during the nonbreeding season. Five of the eight confirmed mortalities were suspected to be a result of vehicle collisions. Mortalities during the nonbreeding season were individuals from the three populations, but mortalities during the breeding and return migration seasons were only of individuals from the eastern populations.

Annual survival over a 17-year period averaged 0.87 (95% CI: 0.74–0.98). Eastern populations of the Turkey Vulture exhibited lower survival probabilities (0.72, 95% CI: 0.60–0.81, $n = 13$) compared to central (0.91, 95% CI: 0.87–0.94, $n = 12$) and western (0.97, 95% CI: 0.96–98, $n = 28$) populations. Across all populations, seasonal survival averaged 0.87 (95% CI: 0.75–1). Survival during the breeding (0.97, 95% CI: 0.96–0.98) and outbound migration (1.0, 95% CI: 1–1) seasons was significantly higher than the other seasons. Average survival tended to be higher for nonbreeding (0.81, 95% CI: 0.71–0.88) compared to return migration (0.69, 95% CI: 0.56–0.81) seasons, although CIs overlapped substantially.

The top-ranked model included measures of road density as an important predictor of risk mortality and survival (Table 1). Turkey Vultures had to traverse areas characterized by average road densities of 130.1 m km^{-2} (SE = 5.5) in the breeding season, 151 m km^{-2} (SE = 5.7) in the outbound migration, 173.5 m km^{-2} (SE = 6.7) in the nonbreeding season, and 176 m km^{-2} (SE = 6.1) in the return migration. As expected, the probability of survival was inversely related to road density. The risk of mortality during the year increased with road density ($\beta_{road} = 0.576$, SE = 0.23, $P = 0.01$; Figure 2) and varied through seasons (Table 2, Figure 3), and it was higher during return migration and nonbreeding season ($\beta_{return:road} = 0.947$, SE = 0.344, $P = 0.006$; $\beta_{nonbreeding:road} = 0.641$, SE = 0.636, $P = 0.314$). Conversely, mortality risk was lowest

TABLE 2. Parameter estimates and 95% CI of the top-ranked models on effects of road density (road) on annual and seasonal survival of North American Turkey Vultures (*Cathartes aura*) between 2003 and 2019.

Parameter	β	SE(β)	Hazard ratio (95% CI)	Wald *Z*	*P*
Annual survival					
Road	0.576	0.238	1.78 (1.12–2.84)	2.417	0.016
Seasonal survival					
Breeding:road	0.416	0.223	1.52 (0.98–2.35)	1.863	0.062
Outbound migration:road	0.606	0.724	1.83 (0.44–7.58)	0.836	0.403
Nonbreeding:road	0.641	0.636	1.9 (0.55–6.60)	1.007	0.314
Return migration:road	0.947	0.344	2.58 (1.32–5.06)	2.757	0.006

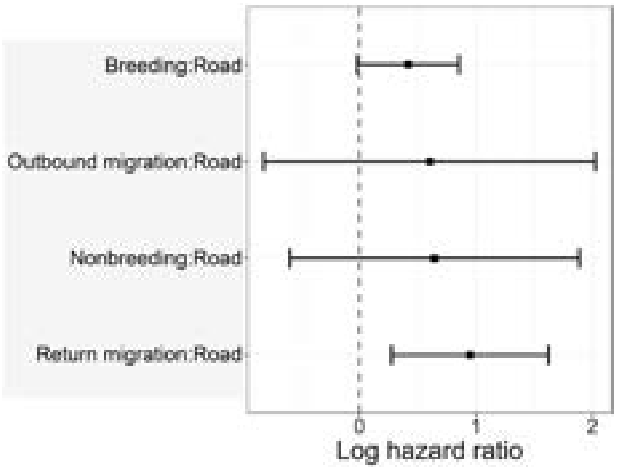

FIGURE 3. Log hazard effect of road density on the seasonal survival probability of North American Turkey Vultures (*Cathartes aura*) between 2003 and 2019. Log hazard ratios greater than zero indicate higher mortality risk and lower survival probability. Horizontal bars correspond to the 95% CI of the log hazard ratio estimation.

during the breeding season ($\beta_{breeding:road} = 0.416$, SE = 0.223, $p = 0.062$). The top-ranked models met the assumption of proportionality (road: $\chi^2 = 0.197$, df = 1, $P = 0.66$; season: road $\chi^2 = 3.52$, df = 4, $P = 0.47$).

DISCUSSION

Although the estimates of annual survival for North American Turkey Vultures in the current study were similar to previous reports, these estimates varied significantly among populations. Western and central populations of Turkey Vultures exhibited higher annual survival probabilities (>90%), while individuals in the eastern populations had the lowest survival rate estimated (72%). This variation in survival rates may be linked to road density which is greater in the eastern regions of North America (Sanderson et al. 2002, Venter et al. 2016). Moreover, Turkey Vultures in eastern North America spend all stages of their annual cycle in this region, thus, may be more at risk than other populations.

The results of our study provided the first estimates on seasonal survival for the Turkey Vulture, with lower survival rates during the nonbreeding and return migration seasons. The low survival during the nonbreeding and return migration seasons likely reflects vultures' poor body condition. The stress imposed by the breeding and migration seasons has been found to lower body condition and reduce survival probabilities (Newton 2004, Newton 2007, Oppel et al. 2015, Duijns et al. 2017). Moreover, migratory Turkey Vultures arriving to the nonbreeding grounds (nonbreeding season) usually have below average body condition which is restored toward the end of the nonbreeding season (Kirk and Gosler 1994).

Despite no apparent mortalities during outbound migration, individuals remained at risk, given the high road density during this portion of the annual cycle. The negative effects of roads and other linear infrastructure on biodiversity have been documented for many decades (Stoner 1925, Forman and Alexander 1998). Over two hundred avian species have been reported to be affected by roads (Benítez-López et al. 2010). Of these, vultures can be attracted to roads (Meunier et al. 2000, Bautista et al. 2004, Lambertucci et al 2009). For instance, Black (*Coragyps atratus*) and Turkey Vultures were more abundant, spent more time, and selected roosting sites near roads given the availability of road-killed carcasses (Coleman and Fraser 1989, Fahrig and Rytwinski 2009, Hill et al. 2021).

Our prediction of reduced survival in landscapes with greater road density was supported by the data and was consistent with similar findings in species of Old World vultures (Arrondo et al. 2020). The negative relationship of survival probability and road density is a response to the availability of carcasses from vehicle collisions (Cristoffer 1991, Clevenger et al. 2003). The spatial variation in road density across the Americas may generate a network of ecological traps for Turkey Vultures induced to stop in areas of greater road-kill abundance (Schlaepfer et al. 2002). The hazards generated by these potential traps are spatially and temporally variable and may exert important consequences, such as the spatio-temporal synchronization of survival rates (Schaub et al. 2005, Jenouvrier et al. 2009). However, the potential benefits of greater road-kill abundance on other vital rates such as fledgling success/recruitment cannot be discounted.

Spatial synchronization of survival rates could occur if individuals from different breeding populations are exposed to similar hazard conditions for a short time period such as migration (Schaub et al. 2005). During migration, Turkey Vultures gather annually for a period of no more than 40 days, particularly in Middle America, where individuals from central and western North American populations overlap during outbound and return migrations. Spatial synchronization of survival (or mortality) rates along with increased risk during the nonbreeding and migration seasons could cause a significant loss of individuals and, therefore, represent a population limiting factor and disruption of ecological services provided by this species in both the breeding and nonbreeding grounds.

The negative impact of roads on Turkey Vultures goes beyond the ecological aspect. Road-killed animals can act as a magnet for vultures and can increase the occurrence of vulture–vehicle collisions and potentially aggravate human–wildlife conflicts (Hill et al. 2021). This highlights the need to implement more permanent and intensive road-kill removal plans as mitigation measures (Jacobson 2005) to reduce the likelihood of human–vulture conflicts and guarantee Turkey Vulture populations persistence.

Further research efforts are needed to better understand the demography of Turkey Vultures at different stages of their lifespan, and in different scenarios. For instance, survival rates between sexes amongst all age classes remain largely unstudied. Given that we only analyzed data collected on adult birds (after the second year), future studies on survivorship and mortality factors of young birds (from hatching to second-year birds) may provide additional information on the life history of the Turkey Vulture. We emphasize the need for studies focusing on the impact of other linear infrastructures (e.g., railways and power lines) and the management of human–vulture conflicts (through vulture depredation permits) that can compromise the long-term survival not only of Turkey Vultures but also the scavenger assembles and the ecosystem services these provide.

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Ethics statement

All birds were captured, handled and tagged following protocols and permits issued by the U. S. Geological Survey (Federal Bird Banding Permits 22749 and 06859), and the Canadian Wildlife Service Bird Banding Office (Permit 00460).

Author contributions

A.N.R., K.L.B., and F.J.V. conceived the idea. K.L.B., D.R.B., J.F.T., M.L.A. and B.M.K. collected and provided the data. A.N.R. and F.J.V. analyzed the data and wrote the paper. All authors provided input, reviewed, and edited the manuscript.

Data availability

Analyses reported in this article can be reproduced using the data provided by Naveda-Rodriguez et al. (2023).

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