Avian Conservation and Management

Evaluating demographic habitat partitioning and its consequences during the non-breeding season in Loggerhead Shrikes

Evaluación de la partición demográfica del hábitat y sus consecuencias durante la época no reproductiva en *Lanius ludovicianus*

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ABSTRACT. The non-breeding season is an understudied, yet likely critical, period for many species. Understanding species' resource requirements, and determining when limited resources and increased densities may lead to intraspecific competition and demographic partitioning, may aid species conservation efforts. Monitoring species' resource requirements during the non-breeding season may be more important in highly modified ecosystems, such as intensive agricultural landscapes, where anthropogenic pressures may further limit resources. The Loggerhead Shrike (*Lanius ludovicianus*) is a rapidly declining avian species that winters in agricultural areas in the southeastern United States, but little is known about their ecology or potential demographic partitioning in this context. To fill these knowledge gaps, we compared multi-scale habitat selection, survival, and space use across age and sex classes of shrikes inhabiting an agricultural landscape in Arkansas, USA. We found that habitat selection differed among demographic classes. Specifically, females preferred areas with more fallow cover, utility wires, and anthropogenic perches, whereas males preferred areas with more agricultural fields and ditches and less soybean cover. However, overall, shrikes exhibited numerous similarities in habitat selection, generally preferring areas with greater developed land cover (within a predominantly agricultural landscape), greater water availability, and taller perches. Despite the observed variability in habitat selection, no differences in apparent seasonal and annual survival rates or home range size existed among groups. However, non-breeding dispersal distance between years differed by age class, with older individuals being more site faithful than younger individuals. We suggest that the demographic habitat partitioning we detected may reflect adaptive differential life history strategies associated with age and sex classes, but further study of habitat selection by Loggerhead Shrikes across seasons and habitat types will help clarify the variation, importance, and potential carry-over effects of non-breeding habitat partitioning.

RESUMEN. La época no reproductiva es un periodo poco estudiado, aunque probablemente crítico, para muchas especies. Comprender las necesidades de recursos de las especies y determinar cuándo la limitación de recursos y el aumento de las densidades conducen a la competencia intraespecífica y a la partición demográfica, pueden ayudar a los esfuerzos de conservación de las especies. El seguimiento de las necesidades de recursos de las especies durante la época no reproductiva puede ser más importante en ecosistemas muy modificados, como los paisajes agrícolas intensivos, donde las presiones antropogénicas pueden limitar aún más los recursos. *Lanius ludovicianus* es una especie de ave en rápido declive que pasa el invierno en zonas agrícolas del sureste de Estados Unidos, pero se sabe poco sobre su ecología o su posible partición demográfica en este contexto. Para llenar estos vacíos de conocimiento, comparamos la selección de hábitat a múltiples escalas, la supervivencia y el uso del espacio a través de las clases de edad y sexo de individuos de *L. ludovicianus* que habitan un paisaje agrícola en Arkansas, EE.UU. Encontramos que la selección de hábitat difería entre clases demográficas. Específicamente, las hembras prefirieron áreas con más cobertura de barbecho, cables de servicios públicos y perchas o posaderos antropogénicos, mientras que los machos prefirieron áreas con más campos agrícolas y zanjas y menos cobertura de soja. Sin embargo, en conjunto, los individuos mostraron numerosas similitudes en la selección de hábitat, prefiriendo en general las zonas con mayor cobertura de tierra urbanizada (dentro de un paisaje predominantemente agrícola), mayor disponibilidad de agua y posaderos más altos. A pesar de la variabilidad observada en la selección del hábitat, no existen diferencias entre los grupos en cuanto a las tasas de supervivencia estacional y anual o el tamaño del rango de hogar existente entre grupos. Sin embargo, la distancia de dispersión no reproductiva entre años difirió según la clase de edad, siendo los individuos de mayor edad más fieles al lugar que los más jóvenes. Sugerimos que la partición demográfica del hábitat que detectamos puede reflejar estrategias vitales adaptativas diferenciales asociadas a las clases de edad y sexo, pero un estudio más detallado de la selección de hábitat por parte de *L. ludovicianus* a lo largo de las estaciones y tipos de hábitat ayudará a clarificar la variación, importancia y potenciales efectos de arrastre de la partición del hábitat no reproductivo.

Key Words: *agricultural landscape; apparent survival; habitat segregation; habitat selection; Lanius ludovicianus; non-breeding ecology; site fidelity*

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INTRODUCTION

A more comprehensive understanding of full annual cycle requirements can be crucial to the successful conservation of species (Giannico and Hinch 2003, Rödel et al. 2004, and Kuhn and Vander Wall 2008). For species that have complex life histories, such as migratory birds, full annual cycle monitoring requires following species across all stages of their annual cycle (i.e., throughout the breeding season, fall migration, non-breeding season, and spring migration). The majority of studies have focused on the breeding season, whereas the non-breeding period is often critical but less studied (Jansson et al. 1981, Beatty et al. 2014). For birds in particular, non-breeding periods can be challenging because winter population densities increase following fall migration and harsh conditions lead to reduced resources (Gill et al. 2001, Norris et al. 2004). The resulting competition and resource scarcities can result in increased mortality rates during the winter and subsequent spring migration periods, or carry over to the breeding season, resulting in decreased fecundity (Rockwell et al. 2012, Tanner et al. 2017).

One potential consequence of increased densities of wintering individuals vying for limited resources is habitat, or resource, partitioning. If conspecifics from disparate breeding regions converge on wintering grounds, individuals may partition non-breeding habitat based on various individual factors, including sex, age, and/or social dominance. Demographic habitat partitioning on the non-breeding grounds has been observed in a variety of migratory bird species (Ornat and Greenberg 1990, Conway et al. 1995, Zharikov and Skilleter 2002), and this pattern is particularly well-documented in the American Redstart (*Setophaga ruticilla*; Sherry and Holmes 1989). Marra and Holmes (2001) suggest that this demographic habitat segregation results from the dominant social behavior of, primarily, older males excluding both younger and female individuals from optimal habitats. Demographic partitioning of habitat is known to occur and has most often been studied in relatively pristine environments not yet drastically altered by human activity (Marra and Holmes 2001, Kolts and McRae 2017). However, partitioning and competition may also occur, and potentially be more severe, in heavily modified ecosystems (Dinkins et al. 2014) where securing appropriate habitat and resources may become challenging (Johnson et al. 2006). Because humans continue to dramatically alter natural habitats worldwide, understanding how these changes may affect habitat selection and demographic partitioning for vulnerable species is important to predict and mitigate these impacts through more targeted conservation strategies.

When demographic-based habitat partitioning occurs, it may have several consequences for individuals. Besides direct effects on fitness through reduced survival (Sherry and Holmes 1996) or impaired physiological condition (Marra and Holberton 1998), partitioning may affect other ecological metrics with indirect fitness consequences. Site fidelity and home range size represent two such metrics that may vary in the presence of competition and also indirectly reflect habitat quality and individual fitness (MacLean and Seastedt 1979, Lanyon and Thompson 1986, Noel and Chandler 2008). For example, larger home ranges can indicate poorer quality habitats (Godet et al. 2018), and differences in home range sizes among demographic groups may suggest an ideal despotic distribution in which some individuals force others into suboptimal habitats (Fretwell and Lucas 1969, Calsbeek and

Sinervo 2002). Strong site fidelity may indicate high habitat quality during both breeding (Schmidt 2001) and non-breeding (Sherry and Holmes 1996) seasons. Individuals forced into suboptimal habitats by competitors may experience reduced non-breeding survival rates due to insufficient resources, or reduced annual return rates due to their dispersal in search of more optimal and available habitats.

One declining, partially migratory species for which the non-breeding season remains poorly studied is the Loggerhead Shrike (*Lanius ludovicianus*; hereinafter "shrike"). Shrikes are predatory, grassland-associated songbirds that rely on relatively open habitats interspersed with ample perching sites from which they perform their preferred sit-and-wait foraging strategy (Panov et al. 2011). Since the 1940s, shrikes have declined at an estimated annual rate of 3.7% across their range in North America (Pardieck et al. 2019). Much research has occurred in response to these declines, but most studies have focused on the breeding season and relatively natural habitats (e.g., Yosef and Grubb 1994, Becker et al. 2009, Shen et al. 2013). A majority of studies have documented relatively high rates of both reproductive success and unoccupied yet seemingly suitable breeding territories (Brooks and Temple 1990, Chabot et al. 2001). Thus, factors associated with the non-breeding season, potentially leading to high mortality (O'Brien and Ritchison 2011), may be disproportionately responsible for observed population declines, but this hypothesis has yet to be explicitly tested.

Multiple extrinsic factors at various scales may contribute to high mortality for shrikes during the non-breeding season. Some potential factors, specifically in agricultural habitats, are habitat loss and degradation (Dechant et al. 2002), roadside mortality (Blumton 1989, Hager 2009), and pesticide exposure (Bellar and Maccarone 2002). Intraspecific competition may serve as an additional source of increased mortality during migration and the non-breeding season. Competition may be a greater factor during periods of increased densities, such as instances where sedentary and migratory shrikes co-occur on shared wintering grounds, and can result in demographic habitat partitioning and differential age- or sex-specific fitness (Sherry and Holmes 1996, Pérez and Hobson 2009). Any combination of these factors may be contributing to shrike declines, but little is known about habitat selection and partitioning, space use, or survival of shrikes during the non-breeding season, especially in highly modified agricultural landscapes.

To fill these knowledge gaps, we conducted a three-year study of marked shrikes during the non-breeding season in agricultural areas of northeastern Arkansas, USA. Specifically, we (1) evaluated habitat selection by shrikes and compared selection among demographic groups, (2) estimated annual and within-season apparent survival, site fidelity, and minimum home ranges of shrikes and compared these metrics across demographic groups, and (3) modeled relationships among habitat features, sex, age, and apparent survival. Although relatively exploratory, we broadly hypothesized that shrikes would prefer specific habitat features associated with agricultural systems in this region, that preferences would differ by sex and age, and that apparent survival and territory size would differ by sex and age. More specifically, we predicted that older individuals would maintain smaller territories and exhibit greater apparent survival and site fidelity because they likely occupied higher-quality territories. In total,

this study investigates the process and extent of habitat partitioning in a relatively common, but severely understudied system: a partial migrant population during the non-breeding season in an intensive agricultural landscape.

METHODS

Study area

The Lower Mississippi Alluvial Valley (hereinafter "LMAV") of the central United States has undergone decades of extensive conversion to intensive row-crop monocultures (Twedt and Loesch 1999, Stanturf et al. 2000). The region previously consisted of widespread bottomland hardwood forests and large expanses of prairie and other grassland habitats (Stanturf et al. 1998, King et al. 2006). Shrike populations that previously inhabited these natural grasslands now occupy agricultural areas both in the LMAV and across the shrike's range (Pruitt 2000, Donahue et al. 2021). Our study was conducted in Craighead and Poinsett Counties (35.44°N-36.00°N, 90.28°W-91.04°W) within the LMAV of northeastern Arkansas, USA (Fig. 1). Together, these two counties cover ~3800 km², of which over 75% has been developed or converted to agriculture (Twedt and Loesch 1999, Dosskey et al. 2012). Shrikes in this area, which include both year-round residents and winter migrants, are almost exclusively found in close association with agricultural fields (Panov et al. 2011). The agricultural areas within our study site consisted of mainly row crops (~75%), interspersed with some forest (15%), developed area (7%), and pasture (3%; Homer et al. 2015). Throughout our study, the major crop types were soybeans (*Glycine max*; ~53%), rice (*Oryza sativa*; ~21%), cotton (*Gossypium hirsutum*; ~10%), and corn (*Zea mays*; ~7%), and the remaining fields were planted with various winter cover crops (e.g., peanuts (*Arachis hypogaea*), winter wheat (*Triticum aestivum*), and alfalfa (*Medicago sativa*); USDA-NASS 2018). Climatically, our study area has relatively mild and wet winters (mean temperature = 6.3 °C; range = 1.4–11.1 °C; mean precipitation = 41.9 cm; average snowfall = 8.3 cm). The winter seasons included in this study (2016–2019) were slightly warmer and wetter than average (mean temperature = 6.9 °C; range = 1.8–11.6 °C; mean precipitation = 51.3 cm; average snowfall = 3.8 cm; Palecki et al. 2021).

Fig. 1. Capture locations of banded Loggerhead Shrikes (*Lanius ludovicianus*; n = 72; white points) across the study area of Craighead and Poinsett Counties (shaded red in the inset map of Arkansas) in northeastern Arkansas, USA during the 2016–2018 non-breeding season.
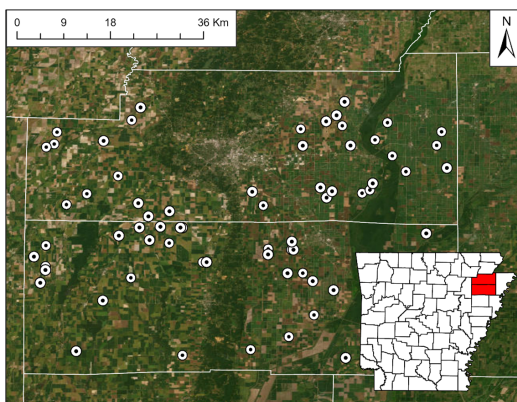
Field methods

Capture and marking

Fieldwork took place during three non-breeding seasons (November through February; 2016–2017, 2017–2018, and 2018–2019). During the first two years of study, we captured shrikes with specialized Potter Traps baited with mice (Collister and Fisher 1995). Once captured, we aged each shrike as either a young, hatching-year/second-year (HY/SY) bird or an older, after-hatching-year/after-second-year (AHY/ASY) bird based on molt limits (following Pyle 1997). HY/SY birds that were resighted the year following banding were then classified as AHY/ASY birds. We also sexed each shrike based on the angle and extent of the white edging on the sixth primary feather of the wing (following Morgan and Chabot 2020). We recorded standard morphometrics (e.g., mass and wing chord) and marked individuals with federal, numbered stainless steel bands and a unique combination of three colored, plastic double-overlap bands (Haggie Engraving). Color bands, which were sealed by soldering to reduce the likelihood of removal by the bird, allowed for the subsequent identification of individuals without recapture.

Resighting efforts for assessing habitat selection, space use, and apparent survival

During November 2017–February 2018 and November 2018–February 2019, we conducted surveys to resight individuals that were either banded or relocated the previous year. These data were collected to calculate an apparent annual survival estimate. We searched for each individual at least three times, for 1 hour during the first attempt and for 30 min each subsequent attempt, during each non-breeding season. Resighting attempts occurred within a radius of 2 km around the capture locations, the last observed locations, and, when applicable, additional unique observed location(s) from previous non-breeding seasons. In addition, field observers (n ≥ 5 per season) closely examined all shrikes encountered opportunistically throughout the field season; this sample consisted of > 120 unmarked shrikes per year. Through this extensive, systematic, and opportunistic search effort, we are confident that we identified the majority of individuals that returned to or stayed within the borders of our study area.

During November 2016–February 2017 and November 2017–February 2018, we conducted regular weekly surveys to resight banded individuals. These weekly resighting data were gathered to calculate an apparent within-season survival estimate. We attempted to resight each banded shrike once per week starting the week following banding or relocating (if originally banded the previous season) and continuing until the end of the non-breeding season. We considered 1 March the end of the non-breeding season because it corresponds with the approximate date shrikes begin to engage in courtship behaviors and form pairs in this area. During each resighting attempt, we spent 30 min searching for birds by driving all roads within 2 km of the last known location, scanning all perches using binoculars, and examining all observed birds with spotting scopes to determine identity. These roads are mainly county roads present in a consistent grid (averaging 1.5 x 1.5 km) throughout the study area, and in conjunction with the long-range visibility afforded by the open agricultural landscape, we believe this grid allowed for high detectability of shrikes. As evidence of this, we tagged four birds with very high frequency (VHF) radio transmitters during the first season and found no improvement in our ability to resight

shrikes, so we discontinued the use of these devices out of concern for their potential to alter bird behavior or survival (Barron et al. 2010).

Multi-scale habitat measurements
We chose habitat features a priori that we considered of potential importance for shrikes during the non-breeding season in agricultural landscapes. Shrike habitat selection has been previously studied in grassland habitats (Bellar and Maccarone 2002, Dechant et al. 2002), and we used these past studies as a basis for choosing habitat variables to measure. Utility wires and vegetation along roadsides and in irrigation ditches provide potential perches and semi-natural habitat for shrikes (Eseley and Bollinger 2001), so we focused on a suite of variables (e.g., perch height, ditch presence and dimensions, water presence, and right-of-way grass dimensions) related to these features and their surrounding habitat (Table 1 lists justifications for inclusion of habitat variables).

Once a bird was resighted, we allowed it to move once from its initial perch to reduce the likelihood of bias in resighting (e.g., it may be more likely that we would detect an individual on a utility wire than on cotton stubble). We then used this second location, even if it simply returned to its initial perch, as the "used" point and the center point for measuring habitat characteristics. At this point, we immediately estimated perch height using a range finder and clinometer and assessed several potentially temporary habitat features. These temporary features included the presence or absence of water, such as in ditches or fields, the presence or absence of crops, and whether fields had evidence of tillage or burning at 5-m and 11-m radii marked with a tape measure around the perch site (Table 1). The 5-m radius was used to capture microhabitat features immediately under perched shrikes, and the 11-m radius was used to follow standardized perch-site vegetation collection practices (James and Shugart 1970). We then assessed these habitat features at a paired, randomly generated available point for each resight location. To select paired available points, we randomly generated numbers representing a direction (0–359°) and distance (25–300 m) from the perch location. Because some shrikes were located ~400 m apart, we estimated that 25–300 m would be a plausible and realistic range for shrikes to travel without infringing on a neighboring home range. A single perch nearest to the randomly generated location served as the available point where measurements were made. Viable available perches included any elevated substrate (e.g., continuous wires, isolated trees, agricultural equipment, and crop stubble) from which a shrike may forage.

At the end of each field season, we returned to all used and available locations to measure permanent habitat characteristics within 100-m and 250-m radii (Table 1). We selected these broader radii based on our general observations of shrike movements in the region, and our judgment of what scales might best represent a non-breeding foraging or home range patch while limiting the scale to remain logistically feasible and keep estimation error as low as possible. We estimated perch availability by counting the total number of woody and non-natural perches up to 50 (or > 50) perches and up to 100 (or > 100) perches at 100-m and 250-m radii, respectively. We also estimated the availability of continuous perches provided by utility wire by measuring the total length of utility wire at 100-m and 250-m radii. Non-natural

perches included any elevated object, excluding utility wires, from which a shrike may forage, and woody perches included any snags, trees, shrubs, etc. in the area. We characterized right-of-way areas by including the total number and average width of ditches and the average width and height of bordering grasses, estimated with a meter stick, within 100-m and 250-m radii.

At the broadest landscape scale (500-m radius), we measured land cover and crop stubble type proportions using data from Cropscape (USDA-NASS 2018) generated during the growing season immediately preceding each respective non-breeding season. We divided land cover into the following categories: rice, cotton, corn, soybean, fallow field, forest, and developed. Our "developed" land cover category includes a variety of land use types as classified by Cropscape, ranging from small dirt roads to intensive urban cities. In our study area, "developed" land cover typically consisted of dirt roads and small residential lots or cemeteries, often with a few trees. These small, developed areas were interspersed among vast agricultural fields. The percentage of each land/crop type was then calculated within a 500-m buffer around each used and random available point in ArcGIS version 10.3.1 (ESRI 2011).

Data analysis

Habitat selection
We constructed generalized linear mixed models (GLMMs) in Program R 3.5.3 (R Core Team 2019) with the lme4 package (Bates et al. 2015) to assess habitat selection by all shrikes combined and by each demographic group separately (females, males, HY/SY individuals, AHY/ASY individuals). We used location points and associated habitat data from a total of 63 individuals to build habitat selection models for each group; of these individuals, 16 were resighted and monitored for both years of the study and contributed two years of habitat use data. For grouping by sex, individuals monitored for two consecutive years included seven females and nine males. For grouping by age, seven of the 16 birds were younger (HY/SY) birds in 2016–2017 that became older (AHY/ASY) birds in 2017–2018 whereas the other nine were older (AHY/ASY) birds during both years. The dependent variable for all models was the binomial point type: Used or Available. We first conducted pairwise correlation tests among all variables at all scales using the *pairs* function in R and a standard correlation cutoff value ($r = 0.70$; Dormann et al. 2013). If two variables were > 70% correlated, we removed one of the two variables by evaluating their biological significance and potential for measurement error. We then attempted to replicate the hierarchical, behavioral process of habitat selection by birds (McGarigal et al. 2016) by building models with variables from the broadest (500-m) to finest (5-m) scales. At each scale, we compared models using Akaike's Information Criterion with small-sample correction (AIC_c) and considered all models $\Delta AIC_c \leq 2$ to be equivalent (Akaike 1974, Burnham and Anderson 1998, Anderson and Burnham 2002). All models included bird identity as a random intercept to account for multiple locations involving the same individuals.

We followed an information-theoretic model selection process by first comparing all univariate and bivariate models including the 500-m land cover data variables and a null model. We then added all combinations of up to two more variables from the 250-m scale to each of the top models from the 500-m scale to create models

Table 1. Habitat variables included in Loggerhead Shrike (*Lanius ludovicianus*) non-breeding habitat selection models based on their potential biological significance.

Variable (unit)	Model code	Measurement method	Biological justification (citations if available)
500-m Scale			
Percent Forest (%)	Forest500	Cropscape and ArcGIS	Forested areas may be avoided by grassland-associated species (Eseley and Bollinger 2001)
Percent Developed (%)	Develop500	Cropscape and ArcGIS	Development may be important if it provides more perching substrates or ideal vegetation (Boal et al. 2003)
Percent Rice (%)	Rice500	Cropscape and ArcGIS	Certain crops may be preferred or avoided for prey visibility and/or availability (Eseley and Bollinger 2001)
Percent Soybean (%)	Soy500	Cropscape and ArcGIS	Certain crops may be preferred or avoided for prey visibility and/or availability
Percent Cotton (%)	Cotton500	Cropscape and ArcGIS	Certain crops may be preferred or avoided for prey visibility and/or availability
Percent Corn (%)	Corn500	Cropscape and ArcGIS	Certain crops may be preferred or avoided for prey visibility and/or availability
Percent Fallow (%)	Fallow500	Cropscape and ArcGIS	Areas may be preferred or avoided for prey visibility and/or availability
250-m Scale			
Wire Length (m)	Wire250	Rangefinder	Wires provide continuous perches (O'Brien and Ritchison 2011)
Woody Perches	NatPerches250	Rangefinder	Certain densities and types of perches may be preferred (Chavez-Ramirez et al. 1994)
Anthropogenic Perches (excluding continuous substrates)	AnthroPerch250	Rangefinder	Certain densities and types of perches may be preferred (Chavez-Ramirez et al. 1994)
Ditches	Ditches250	Rangefinder	Ditches provide potential foraging habitat (Donahue et al. 2021)
Average Ditch Width (m)	DitchW250	Extendable measuring pole	Certain characteristics of ditches may make them more desirable foraging habitat
Average Right-of-way Grass Width (m)	GrassW250	Diameter tape	Certain characteristics of right-of-way grasses may make them more desirable foraging habitat (O'Brien and Ritchison 2011)
Average Right-of-way Grass Height (m)	GrassH250	Meter stick	Vegetative structure may affect prey visibility availability in rights-of-way (O'Brien and Ritchison 2011)
100-m Scale			
Wire Length (m)	Wire100	Rangefinder	Wires provide continuous perches
Woody Perches	NatPerches100	Rangefinder	Certain densities and types of perches may be preferred
Anthropogenic Perches (excluding continuous substrates)	AnthroPerch100	Rangefinder	Certain densities and types of perches may be preferred
Ditches	Ditches100	Rangefinder	Ditches provide potential foraging habitat (Donahue et al. 2021)
Average Ditch Width (m)	DitchW100	Extendable measuring pole	Certain characteristics of ditches may make them more desirable foraging habitat
Average Right-of-way Grass Width (m)	GrassW250	Diameter tape	Certain characteristics of right-of-way grasses may make them more desirable foraging habitat
Average Right-of-way Grass Height (m)	GrassH250	Meter stick	Vegetative structure may affect prey visibility availability in rights-of-way
11-m Scale			
Water Presence	Water11	Visual inspection	Water may attract desired prey or increase prey densities
Crop Presence	Crops11	Visual inspection	Presence or absence of crops may affect prey visibility/availability (Wheelock et al. 2016)
5-m Scale			
Perch Height	PerchH5	Range finder and clinometer/ Extendable measuring pole	Perches of an optimal height for foraging/concealment may be selected (Becker et al. 2009)
Water Presence	Water5	Visual inspection	Water may attract desired prey or increase prey densities
Crop Presence	Crops5	Visual inspection	Presence or absence of crops may affect prey visibility/availability

that combined scales. We restricted each model to contain at most two variables from each scale to limit the number of models built for comparison because we were testing such a large suite of variables. We then compared these combined models to the top models from the 500-m scale, univariate and bivariate models from variables at the next finest scale (250-m), and the null model. This process was then repeated for the 100-m, 11-m, and 5-m scales, respectively. After narrowing down to the final suite of top models, we assessed the importance and directionality of habitat selection for variables included in these models by examining the sign and 85% confidence intervals (CIs) around β coefficients (Arnold 2010). We considered a variable to be of importance if its 85% CI did not overlap zero for the highest-weighted model in which it first appeared. We considered shrikes to "prefer" or "avoid" variables of importance based on the positive or negative directionality of the variable coefficient, respectively. Although our study does not provide a true test of behavioral choice, our definition of preference (or avoidance) is simply that the birds were using resources/habitat features more (or less) than expected by random chance, given their availability on the landscape. To evaluate potential habitat partitioning among demographic groups, we qualitatively compared models and variables of importance among sexes and age classes.

Apparent survival

We built Cormack-Jolly-Seber (CJS) models in Program MARK 6.2 (White and Burnham 1999) to estimate both annual and within-season apparent survival of shrikes. Because our assumed annual detection rate was 100%, our annual apparent survival rate was equivalent to our resight rate. We reported within-season apparent survival estimate as a weekly apparent survival rate obtained from CJS models and then extrapolated this estimate across the 14-week monitoring period to produce an estimate for the entire non-breeding season (mid-November to mid-February). Models were then built and compared using AIC_c values to test for possible effects of sex and age on within-season apparent survival and effects of sex, age, and year at the time of banding on annual apparent survival. We also included bird

Table 2. Habitat features preferred (bold) or avoided (italics) by Loggerhead Shrikes (*Lanius ludovicianus*) during the non-breeding season in northeastern Arkansas, USA based on analyses of datasets that consisted of: (1) male (*n* = 22 individuals in 2016–2017 and 28 individuals in 2017–2018/261 total used points), (2) female (*n* = 11 individuals in 2016–2017 and 17 individuals in 2017–2018/147 total used points), (3) hatching-year/second-year (HY/SY; *n* = 15 individuals in 2016–2017 and 13 individuals in 2017–2018/101 total used points), (4) after-hatching-year/after-second-year (AHY/ASY; *n* = 17 individuals in 2016–2017 and 34 individuals in 2017–2018/307 total used points), and (5) all individuals (*n* = 63 individuals including 16 resighted individuals monitored for two years /408 total used points). Values were derived from the top habitat selection model for each demographic group; variables of importance were inferred when 85% CI of β coefficients did not overlap zero in the heaviest weighted model. A dash represents a non-informative variable for the corresponding demographic group.

Scale (m)	Variable	Male	Female	HY/SY	AHY/ASY	All Individuals
500	% Developed	**0.114 (0.051–0.177)**	**0.201 (0.067–0.335)**	**0.121 (0.059–0.184)**	**0.211 (0.125–0.297)**	**0.13 (0.082–0.178)**
500	% Fallow	-	**0.039 (0.017–0.061)**	-	**0.032 (0.010–0.053)**	-
500	% Soy	*-0.006 (-0.012–(-2.35e-4))*	-	-	-	*-0.006 (-0.011–(-0.001))*
500	% Cotton	-	-	-	-	**0.004 (5.60e-5– 0.009)**
250	Wire Length	-	**0.031 (0.014–0.048)**	**0.015 (0.005–0.024)**	**0.017 (0.006–0.028)**	**0.015 (0.005–0.025)**
250	Anthropogenic Perches	-	**0.008 (0.001–0.015)**	-	-	-
100	Grass Height	-	-	-	**1.006 (0.193–1.818)**	**0.697 (0.105–1.289)**
100	Ditches	**0.205 (0.065–0.345)**	-	-	-	**0.141 (0.030–0.253)**
11	Water Presence	**1.018 (0.714–1.322)**	**1.068 (0.599–1.536)**	**1.09 (0.789–1.390)**	**0.941 (0.625–1.257)**	**0.981 (0.740–1.222)**
11	Crop Presence	**0.647 (0.214–1.080)**	-	**0.672 (0.239–1.106)**	-	-
5	Perch Height	**0.144 (0.111–0.177)**	**0.196 (0.142–0.249)**	**0.147 (0.113–0.180)**	**0.149 (0.117–0.181)**	**0.152 (0.124–0.179)**

identity as a fixed effect in all models because Program MARK does not allow for the inclusion of random effects. After testing for effects of sex and age on within-season apparent survival, we then tested for correlations between within-season apparent survival and important habitat characteristics by adding habitat variables as covariates, hierarchically from broadest to finest scale, following a similar model selection process as used for habitat selection models. Habitat characteristic covariates were those variables that were deemed important from habitat selection analyses (Table 2), averaged across all used points within a non-breeding season for each individual.

Space use and site fidelity
We used the minimum convex polygon (MCP) method to calculate an average shrike minimum home range estimate. We used this method because we had relatively few locations for many of our birds and wanted a simplified estimate of home range that would allow for easier comparison to other studies that also used the MCP method for shrikes (e.g., Yosef and Grubb 1993, Collister and Wilson 2007). For each individual with ≥ 5 resight locations within any one season, we created a 100% MCP, which we considered its minimum home range, using the *MCP* function in the adehabitatHR package (Calenge 2006) in Program R 3.5.3 (R Core Team 2019). Our data included three shrikes for which we had two sets of location points and thus home range size estimates from two consecutive seasons (2016–2017 and 2017–2018). We mapped the resulting shapefiles in ArcGIS version 10.3.1 (ESRI 2011) to calculate the total area covered by each MCP. We evaluated the relationship between minimum home range estimates, log-transformed to fit normality, and year, sex, and age by creating linear mixed models (LMMs) using minimum home range size as the dependent variable and comparing all possible combinations of independent variables. Because we had multiple MCP estimates for individuals that were resighted in subsequent

years and estimates were based on a variable number of resight locations for each bird (ranging from 5 to 13), we included individual identity and the number of resight locations as random effects in these models and compared models using AIC_c.

Finally, we estimated site fidelity as the tendency of a shrike to return to or stay within the same non-breeding home range in subsequent years. Site fidelity was expressed as a measure of annual, non-breeding dispersal calculated as the distance between each individual's first point of relocation during a given year and the first location from the previous year. Our data included eight shrikes for which we had two site fidelity estimates because we found them over three consecutive seasons. We then built LMMs and evaluated the relationship between these dispersal estimates, which were log-transformed to fit normality, and year, age, and sex in a similar manner to the minimum home range evaluation.

RESULTS
During November 2016–February 2017 and November 2017–February 2018, we captured, banded, and monitored 72 shrikes (Fig. 1). These included 48 males, 24 females, 32 HY/SY birds, and 40 AHY/ASY birds. Means are reported with standard errors (mean ± standard error), and β values are reported with 85% confidence intervals.

Multi-scale habitat selection
For habitat analyses, we had 63 individual shrikes with sufficient and 9 with insufficient habitat data; the latter were excluded from habitat selection analyses. During the 2016–2017 season, we recorded habitat data for 8 male HY/SY birds, 13 male AHY/ASY birds, 4 female HY/SY birds, and 7 female AHY/ASY birds. During the 2017–2018 season, we recorded habitat data for 7 male HY/SY birds, 23 male AHY/ASY birds, 6 female HY/SY birds, and 11 female AHY/ASY birds.

When including all shrikes with suitable habitat data (408 used points), seven equivalent top models (ΔAIC ≤ 2) explained habitat selection (Table S1) and suggested collective preference and avoidance of variables at multiple spatial scales (Table 2). At the broadest (500-m) scale, shrikes preferred areas characterized by relatively high proportions of developed land cover and cotton cover and avoided soybean cover. At the 250-m scale, they preferred areas with greater availability of utility wire (used = 230.3 ± 4.2 m; random = 158.9 ± 6.2 m). At the 100-m scale, they preferred areas with more ditches (used = 2.0 ± 0.1 ditches; random = 1.5 ± 0.1 ditches) and taller right-of-way grasses (used = 25.5 ± 1.1 cm; random = 18.6 ± 1.1 cm). At the 11-m scale, shrikes preferred water presence (used = 48.0 ± 2.5% of points; random = 24.0 ± 2.1% of points), and, at the 5-m scale, shrikes preferred taller perches (used = 6.8 ± 0.2 m; random = 3.6 ± 0.3 m). Of these variables, several were also included in top models across all four demographic groups. Regardless of age or sex, shrikes consistently preferred areas with relatively more developed land cover, greater water, and taller perches (Table 2).

Despite some consistencies in habitat selection across all shrikes, we documented variation in a few habitat variables of importance across scales by demographic group. For each of these demographic groups, multiple equivalent top models explained habitat selection (Tables S2–S5). With respect to age, older shrikes (AHY/ASY) preferred greater fallow field cover at broad scales and taller right-of-way grasses at finer scales, whereas young (HY/SY) shrikes preferred crop presence at fine scales (Table 2). With respect to sex, males avoided soybeans at broad scales and preferred ditches and crop presence at finer scales (Table 2). Females preferred fallow field cover at broad scales and more anthropogenic perches and greater wire availability at slightly finer scales (Table 2).

Apparent survival
Within seasons, weekly apparent survival was 95.6 ± 1.0% (CI: 94.0, 97.0) and seasonal apparent survival was 53.0 ± 8.1% (CI: 40.3, 65.6). Annual apparent survival was 43.3 ± 5.2% (CI: 35.8, 50.8). Return rates based on resighting efforts fluctuated slightly among years, with 50% and 36% of the first- and second-year banded cohorts resighted the following year, respectively. Of those banded in 2016–2017 ($n = 36$), 48% of males, 54% of females, 43% of HY/SY birds, and 55% of AHY/ASY birds were relocated the following season. Of those banded in 2016–2017 that returned or were resighted the second year ($n = 18$), 45% of males, 43% of females, 29% of HY/SY birds, and 55% of AHY/ASY birds were relocated during the 2018–2019 season. Of those banded in 2017–2018 ($n = 36$), 28% of males, 45% of females, 50% of HY/SY birds, and 20% of AHY/ASY birds were relocated during the 2018–2019 season. In both within-season and annual models, constant survival was the best-supported model; neither age nor sex improved any models, implying that apparent survival did not vary meaningfully among demographic groups. Additionally, none of the added habitat variables improved models.

Space use and site fidelity
Shrikes had an average minimum home range size of 13.4 ± 2.4 ha ($n = 38$, median = 6.7 ha, range = 0.5–63.6 ha), and 47.4% ($n = 18$) of these home range estimates were smaller than 5 ha. Of those individuals for which MCPs were generated, eight had the

minimum required five points and 11 had ≥ 10 points. Neither age nor sex improved minimum home range models, and thus the top model was the null model. Resighted shrikes dispersed an average of 1534.1 ± 644.2 m ($n = 37$ resighted individuals, median = 324.9 m, range = 11.7–18,224.1 m; Fig. 2) from their previous non-breeding territory. After removing four statistical outliers that were more than 1.5 times the interquartile range above the upper quartile, which included three young (SY) females and one young (SY) male resighted > 2 km away (Fig. 2), the average dispersal distance was 377.4 ± 56.5 m ($n = 33$, median = 266.9, range = 11.7–1336.5 m). Of birds that were resighted, 70% dispersed < 500 m from their original banding site (mean annual dispersal distance = 1.4 km, with 92% of resighted birds found ≤ 2.5 km from the previous year). The top model explaining non-breeding dispersal included age alone (AIC_c weight = 0.40; AHY/ASY β = 2.36, CI = 2.09, 2.65; HY/SY β = 2.88, CI = 2.20, 3.57), with older birds (340.7 ± 63.7 m) returning or staying closer to their previous wintering location than young birds (3284.5 ± 1501.7 m). This pattern remained after excluding outliers.

Fig. 2. Site fidelity (as measured by annual, non-breeding dispersal distances) of resighted Loggerhead Shrikes (*Lanius ludovicianus*) from original banding locations during the non-breeding season in northeastern Arkansas, USA ($n = 37$) based on (a) age and (b) sex. Gray circles represent statistical outliers. Young and old shrikes include hatching-year/second-year and after-hatching-year/after-second-year individuals, respectively.
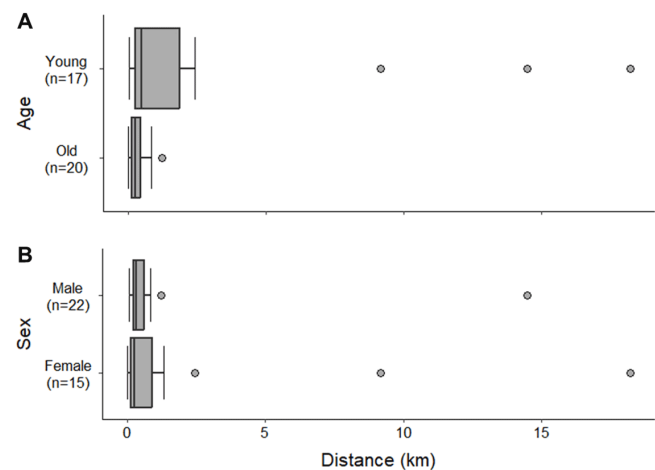
DISCUSSION
Our study reveals several demographic-related differences in habitat selection preferences and site fidelity in non-breeding Loggerhead Shrikes within an agricultural landscape. Sex and age classes differentially preferred and avoided a variety of habitat features whereas other features, such as water presence, taller perches, and developed land cover, were preferred by all groups. Additionally, older individuals exhibited higher site fidelity than younger birds. If variation in habitat selection resulted from competition, such as older or male individuals excluding younger or female individuals, no group appeared to incur short-term fitness costs from occupying suboptimal habitats. Contrary to our predictions, no differences in survival or minimum home range

sizes existed among demographic groups. Shrike site fidelity estimates followed our prediction, with older individuals displaying higher site fidelity. Finally, overall, we documented relatively high survival rates and site fidelity for a non-breeding shrike population.

The demographic differences in habitat selection that we detected may be driven by multiple non-exclusive factors and may have important implications. First, variable demographic habitat selection may reflect adaptations to unique life history strategies (Parrish and Sherry 1994, Ruckstuhl 2007). This population of shrikes is partially migratory (Donahue and Boves, *unpublished data*), and we likely monitored both migratory and sedentary individuals in this study. Although we could not determine the migratory status of all individuals, some sedentary shrikes were clearly included, and these birds, specifically males, may maintain defensible territories year-round and thus select wintering home ranges that also provide features suitable for future breeding purposes. This pattern has also been observed in King Rails (*Rallus elegans*), with sexual segregation occurring in non-breeding habitat where males overwinter on or near nesting sites from the previous season (Kolts and McRae 2017). In our study, males preferred areas with more ditches, which are important foraging grounds during the non-breeding season (Donahue et al. 2021) and likely continue to be throughout the year. Accordingly, we opportunistically resighted males, as well as several mated pairs, occupying the same areas during the breeding season that we observed them in during the non-breeding season.

Prey segregation and differential foraging behavior present other potential drivers of habitat partitioning (Holm and Burger 2002). Specifically, the tendency for both older and female shrikes to prefer fallow fields in our study may reflect a difference in insect and vertebrate communities among types of land use/crop cover (Preston 1990, Courtalon and Busch 2010, Wheelock et al. 2016). During the winter in this area, Bobowski (2013) found that fallow fields had the greatest densities of rodents, followed by rice stubble fields and soybean stubble fields, respectively. Thus, older shrikes with local experience may specifically prefer fallow fields to target rodent prey, which is more calorie-dense than the invertebrate prey that dominate the shrike diet in this area (Donahue et al. 2021). Older birds likely have shorter prey-handling times, higher energetic returns, and lower overall risks associated with larger prey, whereas, for younger, inexperienced birds, the potential costs may skew foraging decisions toward smaller, safer prey, such as insects (Recher and Recher 1969, Busbee 1976, Berón et al. 2011). Conducting dietary and behavioral studies of uniquely marked shrikes of known age and sex, while also accounting for prey and habitat availability, would help determine if demographic-specific prey selection or foraging behavior occurs.

A final potential driver of partitioning may be related to social dominance (Lynch et al. 1985). If social dominance is influential, as seen with American Redstarts (Marra and Holmes 2001) and Black-and-white Warblers (*Mniotilta varia*; Cooper et al. 2021) in Jamaica, older males would be expected to occupy the highest quality habitat (and competitively exclude others). Although it is not entirely clear what makes "high" quality habitat in these agricultural landscapes, several pieces of evidence provide support for this possibility. For example, only male shrikes

preferred habitat with more ditches and their associated right-of-way areas, which are important foraging areas in our study area as well as other regions (Collister and Wilson 2007, Donahue et al. 2021). In addition, only older shrikes preferred areas with taller grasses adjacent to fallow fields. This preference for taller grasses along the edges of typically bare-ground ditches may reflect a more holistic feature, vegetative heterogeneity, which is often used to describe high-quality shrike breeding habitat in more natural areas (Prescott and Collister 1993, Michaels and Cully 1998).

Regardless of the cause of habitat partitioning, we did not find any demographic groups to experience within- or between-season differences in survival. The overall survival estimate (43%) was greater than those found in three shrike populations in more natural areas (23% in Missouri; Kridelbaugh 1983, 14% in North Dakota; Haas and Sloane 1989, 41% in Indiana; Burton 1990), but slightly lower than two other breeding populations (50% in Virginia; Blumton 1989, 47% in Minnesota; Brooks and Temple 1990). Though our annual survival estimates seem relatively high, longer-term consequences of partitioning may still exist. For example, compensatory strategies such as increased foraging rates may lead to energy depletion for individuals in suboptimal habitats and lead to physiological consequences, including reduced body condition or chronic stress that might result in longer-term carry-over effects on migration timing and reproductive output in the following breeding season (Marra and Holberton 1998). Our annual survival estimates were variable (36–50%) over our two years of resighting efforts, so data collected over longer time periods could be valuable to assess the factors that may influence variability in survival estimates from a single region.

Estimates of non-breeding survival can be used to begin an assessment of one hypothesized driver of shrike population declines: low non-breeding survival (Dechant et al. 2002). To our knowledge, the only previous study estimating within-season, non-breeding survival of shrikes was conducted in hayfields and pastures of the Shenandoah Valley in Virginia where they reported within-season survival rates of only 3%. However, this estimate comes from a single season with a relatively small sample and may reflect the deleterious effects of transmitters used to track the birds (*n* = 18; Blumton 1989). Within-season survival for non-breeding shrikes in our study, at 53%, although still relatively low, was much higher than Blumton's (1989) estimate and is also greater compared to non-breeding survival estimates of other grassland-associated species (28% for Baird's Sparrows (*Centronyx bairdii*) and 32% for Grasshopper Sparrows (*Ammodramus savannarum*); Macías-Duarte et al. 2017). We currently lack comparable survival estimates across seasons and habitat types to objectively evaluate the relative importance of non-breeding survival as a factor of population declines. Migration presents another poorly understood period for shrikes that may reveal high-impact threats to their populations, because migrant subspecies are experiencing some of the greatest declines (Chabot et al. 2018, Sauer et al. 2019). Because competitive exclusion of migrants by residents may negatively impact survival or increase long-distance movements (Brooks and Temple 1990), it would be interesting to compare survival rates among these groups in the partial migrant shrike population in this region. Eventually, an integrated population model for shrikes will be

necessary to understand what periods of their annual life cycles are limiting populations the most (Schaub and Abadi 2011).

Although apparent survival did not differ by age or sex, site fidelity (as measured by annual, non-breeding dispersal) was variable among groups. As predicted, older shrikes maintained more consistent non-breeding home ranges between years than younger shrikes (i.e. older shrikes dispersed shorter distances). The greater site fidelity and preference for both fallow areas, which have greater prey densities (Bobowski 2013), and taller grasses, which are preferred by breeding shrikes in Kansas (Michaels and Cully 1998), by older individuals may suggest that these individuals occupied higher quality habitats and, consequently, did not disperse far between years (Sherry and Holmes 1996). Across all groups, our average dispersal distance estimate of 1.5 km is lesser than that of the only similar estimate of breeding shrikes in shrubland across Canada where the mean dispersal distance was 2.7 km (Collister and De Smet 1997). However, individuals of the closely related Northern Shrike (*Lanius borealis*) display similarly high site fidelity for non-breeding territories (Rimmer and Darmstadt 1996, Small 2017).

We acknowledge the possibility that small sample sizes may have affected some of our results and this should be considered when using or comparing these estimates in the future. This is especially true for home range and demographic-specific survival estimates. For example, the shrikes we used for our MCP analysis had an average of eight location points, and 21% of the individuals had the minimum five location points for home range estimation. The issue with estimating home ranges based on small sample sizes is well documented (e.g., Downs and Horner 2008). Thus, our home range estimates should only be considered minimum space requirements for the non-breeding season in this region. For our habitat selection analyses, despite the relatively small sample sizes (and associated lack of statistical power), we were able to detect statistically important variables even for our least sampled demographic group (females), but perhaps additional relationships may be found with greater sample sizes.

Although we detected some demographic-based differences in habitat selection and site fidelity, it is important to note that several habitat features were preferred or avoided by all shrikes. At the broadest scale, shrikes selected for more developed areas; however, in contrast to regions where shrikes inhabit true urban habitats, such as inner-city parking lots (e.g., Boal et al. 2003, Worm and Boves 2019, Krauser and Hill 2023), the developed areas used by shrikes in our study were still quite rural. The developed areas in our study primarily consisted of gravel roads, typically bordered by utility wires for hunting and perching, and sparse residential properties and cemeteries containing a few trees for hunting and eventual nesting purposes. This is generally consistent with a study in Arizona that found breeding shrikes prefer and have greater nesting success in rural, open residential areas, as opposed to highly developed, commercialized areas (Boal et al. 2003). We also found that shrikes collectively avoided soybean stubble fields, which could be related to sparser vegetative cover and lower rodent densities in these fields (Bobowski 2013). At finer scales, all shrikes also preferred taller right-of-way grasses bordering bare ditches and roads, supporting the hypothesis of a preference for vegetative heterogeneity (Michaels and Cully 1998). Continuous wire perches and water-filled ditches are likely crucial features preferred by all shrikes in this landscape. Thus,

from a local/regional management perspective, we suggest focusing on the maintenance of these linear habitats by partnering with public and private landowners to maintain vegetative heterogeneity and ample perching structures in right-of-way areas along agricultural ditches and on residential lots. In total, our results, particularly the relatively high annual survival and site fidelity, indicate that, despite often being considered marginal habitats, these agricultural landscapes can provide critical non-breeding habitat for the declining Loggerhead Shrike. These landscapes should be maintained, and improved upon as suggested, to continue to provide this vital habitat.

Data Availability:

The data/code that support the findings of this study are openly available on GitHub at https://github.com/EmRose102/2016_2019_loggerhead_shrike_nonbreeding_study. All birds were captured and banded under federal bird banding (#23877) and state scientific collection (#040620175) permits and an IACUC protocol (IRBNet1001614-1) approved by Arkansas State University.

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APPENDICES

Table S1. Top habitat selection models ($\Delta AIC_c \leq 2$) for all individuals ($n = 63$ individuals; 408 used points). All fixed and random variables reported and shown if preferred (bolded in green) or avoided (bolded and italicized in red) by shrikes. Number of parameters (K), AIC_c, delta AIC_c (ΔAIC_c), and AIC_c weight reported for model comparisons. All models included PointID and BirdID as random effects.

Model	k	AIC_c	ΔAIC_c	AIC_c Weight
NULL	3	1137.25	172.05	9.60e-39
Year	4	1139.27	174.07	3.50e-39
Year + **PerchH5** + **Water11** + Crops11 + **Ditches100** + **Wire250** + **Develop500** + *Soy500*	11	966.24	1.05	0.13
Year + **PerchH5** + **Water11** + Crops11 + Ditches100 + **GrassH100** + **Wire250** + **Develop500** + **Cotton500**	12	966.90	1.70	0.09
Year + **PerchH5** + **Water11** + Crops11 + Ditches100 + **GrassH100** + **Wire250** + **Develop500** + *Soy500*	12	965.39	0.20	0.20
Year + **PerchH5** + **Water11** + Ditches100 + **GrassH100** + **Wire250** + **Develop500**	10	965.97	0.78	0.15
Year + **PerchH5** + **Water11** + Ditches100 + **Wire250** + **Develop500** + **Cotton500**	10	966.52	1.32	0.11
Year + **PerchH5** + **Water11** + Ditches100 + **Wire250** + **Develop500** + *Soy500*	10	965.19	0.00	0.22
Year + **PerchH5** + **Water11** + Ditches100 + **Wire250** + **Develop500** + Fallow500	10	966.92	1.72	0.09

Table S2. Top habitat selection models ($\Delta AIC_c \leq 2$) for male individuals ($n = 42$ individuals; 261 used points). All fixed and random variables reported and shown if preferred (bolded in green) or avoided (bolded and italicized in red) by shrikes. Number of parameters (K), AIC_c, delta AIC_c (ΔAIC_c), and AIC_c weight reported for model comparisons. All models included PointID and BirdID as random effects.

Model	k	AIC_c	ΔAIC_c	AIC_c Weight
NULL	3	729.69	95.79	2.01e-22
Year	4	731.72	97.83	7.27e-23
Year + **PerchH5** + **Water11** + **Crops11** + **Wire250** + **Develop500**	9	635.63	1.73	0.05
Year + **PerchH5** + **Water11** + **Crops11** + GrassH100 + Ditches100 + **Wire250** + Develop500	11	634.37	0.47	0.10
Year + **PerchH5** + **Water11** + **Crops11** + **Ditches100** + Wire250 + **Develop500**	10	634.07	0.17	0.12
Year + **PerchH5** + **Water11** + **Crops11** + **Ditches100** + Wire250 + **Develop500** + Cotton500	11	635.17	1.27	0.07
Year + **PerchH5** + **Water11** + **Crops11** + **Ditches100** + Wire250 + **Develop500** + ***Soy500***	11	633.90	0.00	0.13
Year + **PerchH5** + **Water11** + **Crops11** + **Ditches100** + Wire250 + **Develop500** + Fallow500	11	635.04	1.14	0.07
Year + **PerchH5** + **Water11** + **Crops11** + **Ditches100** + Wire250 + **Develop500** + Forest500	11	634.94	1.04	0.08
Year + **PerchH5** + **Water11** + **Crops11** + GrassH100 + **Ditches100** + **Wire250** + **Develop500** + Cotton500	12	635.45	1.55	0.06
Year + **PerchH5** + **Water11** + **Crops11** + GrassH100 + **Ditches100** + Wire250 + **Develop500** + ***Soy500***	12	633.94	0.05	0.12
Year + **PerchH5** + **Water11** + **Crops11** + GrassH100 + **Ditches100** + Wire250 + **Develop500** + Fallow500	12	635.25	1.35	0.06
Year + **PerchH5** + **Water11** + **Crops11** + GrassH100 + Ditches100 + **Wire250** + **Develop500** + Forest500	12	634.96	1.06	0.07
Year + **PerchH5** + **Water11** + **Crops11** + **Ditches100** + Wire250 + GrassH250 + **Develop500**	11	635.21	1.31	0.07

Table S3. Top habitat selection models ($\Delta AIC_c \leq 2$) for female individuals ($n = 21$ individuals; 147 used points). All fixed and random variables reported and shown if preferred (bolded in green) by shrikes. Number of parameters (K), AIC_c, delta AIC_c (ΔAIC_c), and AIC_c weight reported for model comparisons. All models included PointID and BirdID as random effects.

Model	k	AIC_c	ΔAIC_c	AIC_c Weight
NULL	3	413.65	79.67	1.06e-18
Year	4	415.71	81.73	3.78e-19
Year + **PerchH5** + **Water11** + Crops11 + **Wire250** + **Develop500** + **Fallow500**	10	335.47	1.49	0.10
Year + **PerchH5** + **Water11** + Crops11 + **Wire250** + NatPerches250 + **Develop500** + **Fallow500**	11	335.51	1.53	0.10
Year + **PerchH5** + **Water11** + Crops11 + **Wire250** + **AnthroPerces250** + **Develop500** + **Fallow500**	11	335.63	1.65	0.09
Year + **PerchH5** + **Water11** + **Wire250** + **Develop500** + **Fallow500**	9	334.55	0.57	0.16
Year + **PerchH5** + **Water11** + **Wire250** + NatPerces250 + **Develop500** + **Fallow500**	10	334.81	0.83	0.14
Year + **PerchH5** + **Water11** + **Wire250** + **AnthroPerces250** + **Develop500** + **Fallow500**	10	333.98	0.00	0.21
Year + **PerchH5** + **Water11** + **Wire250** + Ditches250 + **Develop500** + **Fallow500**	10	335.35	1.37	0.11
Year + **PerchH5** + **Water11** + GrassW100 + **Wire250** + **AnthroPerces250** + **Develop500** + **Fallow500**	11	335.63	1.65	0.09

Table S4. Top habitat selection models ($\Delta AIC_c \leq 2$) for hatching-year/second-year individuals (HY/SY; $n = 28$ individuals; 101 used points). All fixed and random variables reported and shown if preferred (bolded in green) by shrikes. Number of parameters (K), AIC_c, delta AIC_c (ΔAIC_c), and AIC_c weight reported for model comparisons. All models included PointID and BirdID as random effects.

Model	k	AIC_c	ΔAIC_c	AIC_c Weight
NULL	3	729.69	90.84	4.72e-21
Year	4	731.72	92.87	1.71e-21
Year + **PerchH5** + **Water11** + **Crops11** + AnthroPerch100 + **Wire250** + NatPerches250 + **Develop500**	11	639.27	0.42	0.20
Year + **PerchH5** + **Water11** + **Crops11** + AnthroPerch100 + **Wire250** + Ditches250 + **Develop500**	11	639.50	0.65	0.18
Year + **PerchH5** + **Water11** + **Crops11** + AnthroPerch100 + **Wire250** + DitchW250 + **Develop500**	11	639.47	0.62	0.18
Year + **PerchH5** + **Water11** + **Crops11** + AnthroPerch100 + **Wire250** + GrassW250 + **Develop500**	11	639.50	0.65	0.18
Year + **PerchH5** + **Water11** + **Crops11** + AnthroPerch100 + **Wire250** + GrassH250 + **Develop500**	11	638.85	0.00	0.25

Table S5. Top habitat selection models ($\Delta AIC_c \leq 2$) for after-hatching-year/after-second-year individuals (AHY/ASY; $n = 42$ individuals/307 used points). All fixed and random variables reported and shown if preferred (bolded in green) by shrikes. Number of parameters (K), AIC_c, delta AIC_c (ΔAIC_c), and AIC_c weight reported for model comparisons. All models included PointID and BirdID as random effects.

Model	k	AIC_c	ΔAIC_c	AIC_c Weight
NULL	3	857.224	133.700	4.81e-30
Year	4	859.250	135.727	1.75e-30
Year + **PerchH5** + **Water11** + Crops11 + **GrassH100** + Ditches100 + **Wire250** + NatPerch250 + **Develop500** + **Fallow500**	13	724.712	1.188	0.29
Year + **PerchH5** + **Water11** + Crops11 + **GrassH100** + Ditches100 + **Wire250** + DitchW250 + **Develop500** + **Fallow500**	13	725.487	1.963	0.19
Year + **PerchH5** + **Water11** + Crops11 + **GrassH100** + Ditches100 + **Wire250** + **Develop500** + **Fallow500**	12	723.524	0.000	0.52