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Understanding How Agricultural Intensification Impacts Ring-Necked Pheasant Distribution and Survival in Eastern South Dakota

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UNDERSTANDING HOW AGRICULTURAL INTENSIFICATION IMPACTS RING-NECKED PHEASANT DISTRIBUTION AND SURVIVAL IN EASTERN SOUTH DAKOTA

BY

HILARY R. KAUTH

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THESIS ACCEPTANCE PAGE

Hilary Kauth

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

UNDERSTANDING HOW AGRICULTURAL INTENSIFICATION IMPACTS RING-NECKED PHEASANT DISTRIBUTION AND SURVIVAL IN EASTERN SOUTH DAKOTA

HILARY KAUTH

2020

Historically, pheasants (*Phasianus colchicus*) have thrived in South Dakota in conjunction with successful land retirement programs or early farming practices through the 1950s, which created interspersions of agriculture and native landscapes that were ideal for pheasants. Recently, the Prairie Pothole ecosystem has undergone rapid agro-economic expansion, effectively reducing ideal interspersions of native prairie and cropland into agriculturally homogeneous landscapes. Indices of pheasant abundance have suggested persistent population declines since 2008, raising concerns regarding landscape suitability. Our goal was to understand how agriculture intensification impacts pheasant ecology. The objectives were to: 1) estimate overwinter hen probability of survival, resource selection, and mortality risks associated with landscape features; 2) determine pheasant abundance as a function of remotely derived landscape composition and vegetative phenology; and 3) implement low-cost Arduino GPS trackers into our ring-necked pheasant study to improve fine-scale data collection. To accomplish these goals, we captured, collared, and tracked 100 female pheasants annually from December through March in each of three years (2016–2019). Overall, we captured 321 females and recorded 110 mortalities. We implemented low-cost GPS trackers on 35 individuals, resulting in 407 VHF locations and 1,574 GPS locations. This was a 287% increase in data density at only 23% increase in cost. We modeled weekly probability of survival and

Cox proportional-hazard cause-specific mortality rates associated with landscape features. To understand pheasant distribution, we surveyed for and modeled pheasant abundance and distribution seasonally as a function of landscape composition and intra-annual differences in vegetation phenology. Overwinter survival of pheasants (0.66) was highly influenced by snow depth. Pheasants using harvested fields experienced a 421% increase in risk of raptor predation. Additionally, pheasants using emergent wetlands experienced a 58% lower risk of weather mortality. Our distribution model demonstrated that proportion of Conservation Reserve Program grasslands, dormant wetlands, and 30-40% row-crop agriculture within 1.6 km^2 positively influenced pheasant abundance. Alternatively, pheasants were negatively associated with proportion of forests. Agricultural intensification is projected to continue reducing valuable concealment, grassland, and emergent wetland landscapes. As native perennial vegetation is critical to both pheasant abundance and winter survival, large-scale conservation efforts are critical to pheasant population viability. Innovative conservation solutions supplementing current farm bill policies may improve conservation adoption thereby improving pheasant abundance and overwinter survival.

INTRODUCTION

Ring-necked pheasants (*Phasianus colchicus;* hereafter pheasants) are an exotic upland game bird native to Asia. Historical records indicate that the first attempts to introduce the species to the United States occurred in 1773 near present day New York (Trautman 1982). These initial introduction attempts were mostly short-lived and unsuccessful, with more successful introductions occurring in Oregon in 1882 (Trautman 1982). Pheasants were later introduced into South Dakota as game birds at the beginning of the 20th century (Trautman 1982, Flake et al. 2012). Since initial introductions, pheasants have flourished in South Dakota with an estimated population of 4.6 million birds in 2017.

Pheasants use herbaceous vegetation as nesting and brood-rearing cover, emergent wetlands or woody features for overwinter shelter, and agricultural waste grain as winter forage (Bogenschutz et al. 1995, Clark et al. 1999, Gabbert et al. 1999, Taylor et al. 2018). The Prairie Pothole Region, extending from Iowa to Canada, historically embodied this type of mosaic of wetlands and grasslands (Naugle et al. 2001). Moreover, early farming practices through the 1950s further enhanced ideal interspersions of agriculture and native landscapes and allowed pheasants to thrive (Taylor et al. 2018). Recently, the Prairie Pothole ecosystem has undergone rapid agro-economic expansion, effectively reducing ideal interspersions of native prairie and cropland into homogeneous agricultural landscapes (USGAO 2007, Wright and Wimberly 2013, Wimberly et al. 2017). Grassland conversion paired with emergent wetland depletion could have negative implications for nesting, brood rearing, overwinter life stages, or overall pheasant population viability.

Indices of pheasant abundance have suggested persistent population declines since 2008, raising concerns regarding landscape suitability (Fig. 0-1). Since the successful establishment of pheasants to South Dakota in 1908, populations have been highly variable with periods of high abundance documented in the 1930s, 1940s, early 1960s, and late 2000s. These periods of high pheasant abundances have traditionally coincided with periods of untended agricultural lands resulting in greater proportion of cover such as what occurred during the Great Depression era, World War II, and during land retirement programs such as the Soil Bank Program and the Conservation Reserve Program (CRP; Flake et al. 2012). Massive pheasant population declines followed each period of high abundance with reinstated farmland and landscape-level habitat changes during 1937, 1950, 1966, and presently (Flake et al. 2012). Collectively this suggests that pheasants benefit from agricultural development so long as cultivated fields are interspersed with adequate herbaceous cover including grasslands and wetlands. Indeed, previous research has shown pheasants to thrive on landscapes with a complex mosaic of grassland blocks, overwinter cover, and food resources within pheasant home range (Clark et al. 1999).

This study was implemented to understand how modern agricultural intensity between 2008 and 2020 impacts pheasant ecology. In this thesis I used a combination of distribution patterns and winter survival to investigate the role of human land use and agricultural intensity on pheasant population viability on an agricultural landscape near Huron, South Dakota. Specifically, I investigated the degree to which the emerging mosaic of intensive land use for agriculture, remaining natural areas, and the application of managed areas (e.g. food plots, CRP, or shelterbelts) influence pheasant viability on this landscape. The order of this thesis follows a hierarchical view of first examining pheasant distribution patterns and annual landscape requirements, then examining overwinter landscape requirements, and lastly implementing GPS tracking devices to understand fine-scale land use patterns.

The objectives addressed in this study were:

1. Determine species distribution models as a function of remotely sensed landscape composition and vegetative phenology variables.
2. Determine winter resource selection of female pheasants.
3. Model cause-specific mortality risk of landscape use for female pheasants.
4. Estimate female pheasant overwinter probability of survival and model environmental factors influencing survival.
5. Implement low-cost Arduino GPS trackers into a ring-necked pheasant study.
6. Assess the practicality, accuracy and feasibility of building Arduino-based GPS trackers for wildlife research without previous engineering experience

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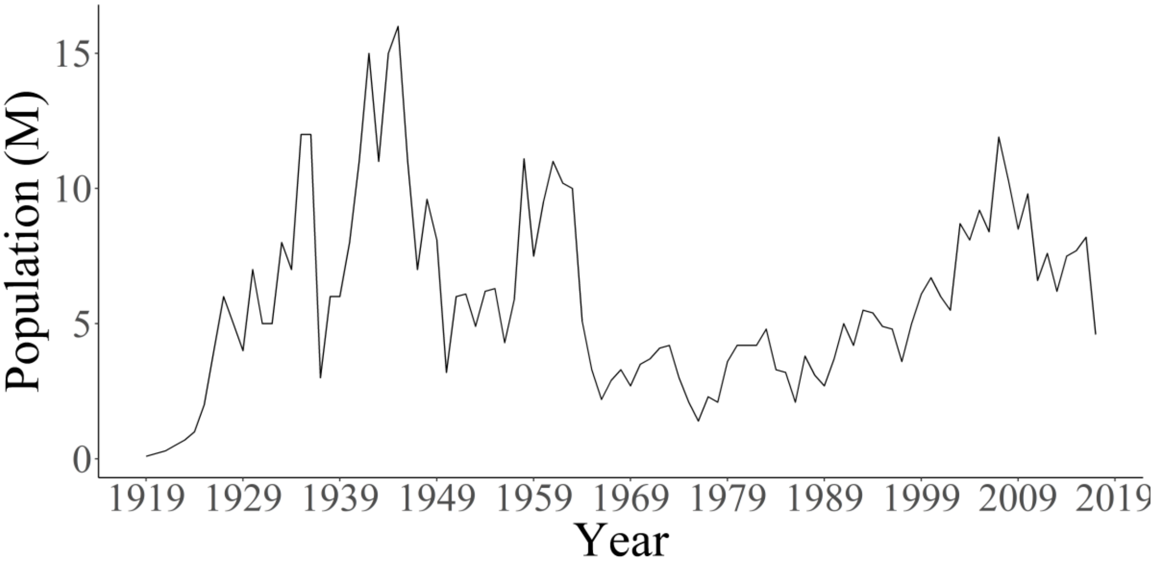
Fig. 0-1. Preseason population estimates for ring-necked pheasants in South Dakota generated from statewide annual pheasant per mile indices. Higher abundances occur with periods of idle or retired landscapes during the Great Depression, World War II, the Soil Bank Program, and the Conservation Reserve Program.



CHAPTER 1: RING-NECKED PHEASANT DISTRIBUTION FROM A BIRD'S EYE VIEW

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ABSTRACT

Indices of ring-necked pheasant (*Phasianus colchicus*) abundance for South Dakota suggest persistent population declines since 2008, raising concerns regarding landscape suitability. Species distribution models are an effective tool for understanding population responses to rapidly changing landscapes and identifying priority areas for conservation spending. Applications of remotely derived landscape data increase the use of distribution models across expansive regions at fractional costs of field-based data collection. We parameterized a species distribution model as a function of landscape composition and intra-annual landscape changes to understand how agricultural intensification influences pheasant abundance and distribution. We expected pheasants to exhibit clustered distribution patterns around landscape mosaics encompassing small agricultural fields, grasslands, and emergent wetlands. Our results demonstrated that proportion of Conservation Reserve Program grasslands, dormant wetlands, and 30-40% row-crop agriculture within 1.6 km^2 positively influence pheasant abundance. Conservation Reserve Program grasslands, wetland, and productive vegetation provide perennial cover that pheasants require year-round. Adversely, pheasants were negatively associated with forests. Broad-scale agriculture intensification has negative implications for pheasants, which rely on complex landscape mosaics. Ideal landscape mosaics of interspersed agriculture, grassland, and wetlands will continue to fragment and cause loss of connectivity, impacting distribution and persistence of pheasant populations.

INTRODUCTION

The Prairie Pothole Region, extending from Iowa to Canada, was historically a mosaic of inter-juxstaposed wetlands and grasslands (Naugle et al. 2001). Over the last quarter century, the Prairie Pothole ecosystem has undergone rapid agricultural conversion with multiple agro-economic expansions that have effectively reduced the area of native tallgrass prairie and emergent wetland landscapes (Wright and Wimberly 2013). In South Dakota, an additional 0.5 million acres of grassland were converted to row-crop agriculture from 2006–2011, further transforming remnant interspersions of native prairie and cropland into homogenously cultivated landscapes (Wright and Wimberly 2013, Wimberly et al. 2017). Rapid widespread landscape transformations are projected to continue as Conservation Reserve Program (CRP) contracts expire, commodity prices remain high, and technology advances (Wright and Wimberly 2013). Widespread landscape transformations likely disrupt land use and connectivity for many wildlife populations within the Prairie Pothole Region.

Indices of ring-necked pheasant (*Phasianus colchicus*) abundance for South Dakota suggest persistent population declines since 2008, raising concerns regarding landscape suitability (South Dakota Departments of Game 2018). Causes of diminishing landscape suitability are multifaceted but likely include altered farming practices resulting in widespread conversions of grassland to cropland (Reitsma et al. 2014). Early farming practices through the 1950s using rudimentary four-bottom plows, small seed drills, and manual weed removal, created ideal interspersions of small agricultural fields with weedy overstory, hay, pasture and native vegetation cover (Flake et al. 2012, Taylor et al. 2018). Intensive landscape transformations between 2008 and 2020 have reduced interspersions of grassland and emergent wetlands to below optimal levels creating an uneven concentration of resources that may alter population distribution and abundance (Beer and Van Aarde 2008, Wright and Wimberly 2013). The advent of modern farming practices with larger and more efficient seed drills and row-crop planters has increased productivity and escalated landscape conversion (Flake et al. 2012). Moreover, implementation of genetically modified drought and herbicide-resistant seeds has resulted in ‘clean’ agriculture with increased application of chemical weed control. Net results of modern farming practices between 2008 and 2020, are grassland loss, increased monocrop agriculture, larger agricultural fields, loss of annual weeds, and reductions in pheasant abundance across much of South Dakota (Flake et al. 2012).

Pheasants thrive under complex landscapes encompassing grassland blocks, overwinter cover, and food resources (Clark et al. 1999). Pheasants use herbaceous vegetation as nesting and brood-rearing cover, emergent wetlands for overwinter shelter, and agricultural waste grain as forage (Bogenschutz et al. 1995, Clark et al. 1999, Gabbert et al. 1999, Taylor et al. 2018). Wildlife species often exhibit hierarchical landscape selection with broad-scale selection occurring between landscape types and fine-scale selection occurring within landscapes (Johnson 1980, Wood et al. 2012). For example, pheasants select grasslands during spring and summer for nesting and brood rearing at broad scales but select vegetative structures >30 cm with 100% visual obstruction and greater vegetative diversity within grasslands at finer scales (Winter et al. 2005, Taylor et al. 2018). Differences in landscape selection can occur due to vegetation structure or intra-annual changes in phenology. Intra-annual changes in vegetation structure can partition individuals within and among landscapes (Wood et al. 2012). For example, pheasants may utilize cool season grasses during nesting, but landscapes dominated by smooth brome (*Bromus inermis*) have little structural resiliency against snow and are considered poor winter habitat (Perkins et al. 1997). Therefore, annual pheasant landscape use and distribution depends on both landscape availability and intra-annual differences in vegetation.

Pheasant population declines in South Dakota have varied spatially, suggesting that certain landscape mosaics are more conducive to pheasant populations than others. Understanding spatial variation in pheasant distributions in response to landscape conversion may help identify landscape sources and sinks, providing land managers with priority conservation areas where management efforts are likely to be maximally beneficial. As such, species distribution models are frequently used to understand population patterns, land-use changes, or identify conservation priorities (Guisan and Zimmermann 2000). Species distribution models forecast predicted use patterns based on known abundance data and inferred environmental relationships (Wen et al. 2015, Fontaine et al. 2017).

Many large-scale pheasant distribution models have inferred relationships between pheasant abundance and remotely derived landscape composition metrics (Nusser et al. 2004, Haroldson et al. 2006, Giudice and Haroldson 2007, Nielson et al. 2008, Jorgensen et al. 2014, Fontaine et al. 2017, Wszola et al. 2017). Rather than relying on cumbersome and costly field-derived landscape data, remotely derived landscape data allows researchers to develop broad-scale inferences (Naugle et al. 2001, Wood et al. 2013). However, commonly applied remotely derived landscape composition metrics are sensitive to classification errors and disregard within-habitat heterogeneity or intra-annual structural changes that are particularly important for understanding fine-scale landscape use (St-Louis et al. 2009). Incorporation of remotely derived image texture as a proxy for within-landscape heterogeneity and normalized-differential vegetation index

(NDVI) as a proxy for intra-annual structural changes can improve pheasant distribution models by accounting for fine-scale landscape use (St-Louis et al. 2014, Hofmann et al. 2017).

We applied species distribution models to estimate pheasant abundance and distribution patterns in a two-stage process by: 1) creating a probability of detection and generating survey abundance estimates; 2) parameterizing a generalized additive model inferring relationships between survey abundance estimates and landscape features; and, 3) extrapolating the generalized additive model to generate region-wide pheasant distribution and abundance patterns. The objective of this study was to generate a species distribution model as a function of remotely sensed landscape composition, within-habitat heterogeneity, and intra-annual landscape changes to understand how agricultural intensification is impacting pheasant abundance and distribution. We predicted that pheasant distribution patterns would cluster around landscape mosaics containing areas of structurally varying grassland, wetland, and agriculture.

STUDY AREA

The study region covered a 270 km^2 area of southwestern Beadle County in eastern South Dakota, United States. Beadle County experiences hot periods during the summer and arctic air surges during the winter resulting in average annual temperatures of 7° C ±14 and cumulative snowfall averages of 157 cm, 2017–2019 (National Oceanic and Atmospheric Administration (NOAA); http://www.noaa.gov/). The study area landscape was 48% row-crop agriculture, 36% pasture, 4% small-grain agriculture, 4% CRP grassland, 4% wetland, 4% developed, and <1% woody features (Fig. 1-1; CropScape; http://nassgeodata.gmu.edu/CropScape/).

METHODS

Surveys

We combined distance sampling techniques with breeding bird survey (BBS) methodology to determine pheasant abundance and distribution (Marques et al. 2007, Thomas et al. 2010, Buckland et al. 2015, Pardieck et al. 2018). Distance sampling is used to estimate a corrected detection function for incomplete detections. We established 24 roadside point-transects randomly throughout our study area. Each transect was 4.82 km long with six fixed survey points starting at 0.32 km and occurring every 0.8 km thereafter. Single-observer surveys were conducted seasonally along each point-transect across two years using distance sampling methodology. At each survey point along the transect, the observer exited the vehicle and actively searched for pheasants using binoculars (Nikon PROSTAFF 3S 10x42, China) for a three-minute focal observation period. Sex and group size were recorded and distance to initial location of the group centroid was estimated using a laser rangefinder for all observations (Leupold RX-850i TBR, China). Rangefinders were capable of accurately recording distances from 6 – ~750 m (± 0.46 m).

Surveys were conducted within two hours of sunrise under optimal pheasant viewing conditions, which included heavy dew or rain during the previous night, sunshine with limited cloud cover, and wind velocities < 12.9 kph (Flake et al. 2012). Surveys were conducted seasonally in spring, summer, fall, and winter, to determine differences in temporal sightability of pheasants and repeated once within each season to alleviate survey biases. Winter surveys occurred between January 2 – February 18 each year and were conducted following heavy snowfall. Spring surveys occurred between April 19 – May 15 each year and took place around the peak crowing period during breeding season (Nelson et al. 1962). Summer surveys occurred between July 24 – August 17 to coincide with South Dakota Game Fish and Parks statewide brood surveys (Flake et al. 2012). Fall surveys were completed between October 1 – November 9, after row-crops (primarily corn (*Zea mays*), wheat (*Triticum sp*.), and soybean (*Glycine max*)) were harvested.

Satellite Imagery Data Collection

Widely available remotely sensed products allow researchers to understand land surface characteristics, land-cover change, vegetation phenology, and structure (Wen et al. 2015). Normalized difference vegetation index (NDVI) measures photosynthetic activity of living green vegetation and is commonly used to predict habitat condition, vegetative cover, and vegetation productivity (Pettorelli et al. 2005, Wood et al. 2012, Pettorelli 2013). Image texture measures horizontal variability in plant growth forms and is used as a proxy of vegetation structure (Haralick, Robert M., Shanmugam. K and Dinstein 1973, St-Louis et al. 2009, 2014, Wood et al. 2012, 2013). The combination of NDVI and image texture metrics will characterize intra-annual landscape change and capture within-habitat heterogeneity representing fine-scale landscape use (St-Louis et al. 2009, Wood et al. 2012).

Red and near-infrared bands from 10-m resolution Sentinel scenes were acquired for 10/28/2017, 01/16/2018, 05/06/2018, 08/06/2018, 10/28/2018, 01/08/2019, 04/08/2019, and 08/06/2019 (downloaded 03/04/2020). We used cloud-free satellite images collected within an average of 10 ± 8 days of each survey to ensure images were not obstructed and adequately represented vegetative conditions at the time pheasant data were collected. NDVI values were calculated from the red and near-infrared bands (Eq.

1) (Pettorelli et al. 2011, Pettorelli 2013). NDVI texture metrics have better explained wildlife patterns than individual band texture metrics likely because they strongly reflect green vegetation, exposing foliage-height diversity (St-Louis et al. 2009, 2014, Wood et al. 2012). Since many texture indices are highly correlated, we selectively calculated first order mean (Eq. 2) and second order contrast (Eq. 3) texture metrics for each landscape within 1.6 km^2 of each survey (Hall-Beyer 2005, St-Louis et al. 2009, Wood et al. 2012, 2013, Hofmann et al. 2017).

NDVI (Equation 1):

$$NDVI = \frac{NIR-RED}{NIR+RED}$$

First order mean (Equation 2):

$$NDVI\ Average = \frac{(NDVI_1+NDVI_2 \ldots +NDVI_n)}{n}$$

Second order contrast (Equation 3):

$$\sum_{i,j=0}^{N-1} P_{i,j}(i-j)^2$$

Each set of texture metrics, first order mean and second order contrast, was modelled seperately and the highest preforming set was included in subsequent models. First order texture metrics calculate variability among 10 m pixels within 1.6 km^2 while second order texture metrics summarize variability between neighborhood 10 m pixels within 1.6 km^2. Second-order texture metrics were calculated in 3 x 3 pixel (30 m x 30 m) windows in four different rotational angles (0˚, 45˚, 90˚ and 135˚) and averaged (St-Louis et al. 2009, Hofmann et al. 2017). We then calculated average values of texture metrics for each landscape type within 1.6 km^2 transect segments and 1.6 km^2 prediction grids.

Broad-scale landscape use was assessed using land-cover data from 2017–2018 (CropScape). We calculated proportion of row-crop agriculture, small-grain agriculture (i.e. winter wheat, spring wheat, durum, barley, oats, winter rye, millet), developed land (i.e. roads, structures), forest, wetlands, pasture, Conservation Reserve Program (CRP) grasslands, and non-CRP grasslands within 1.6 km^2 transect segments and 1.6 km^2 prediction grids using Fragstats software version 4.2. We tested for and did not use correlated variables ($r \geq |0.60|$) in models (Green 1979).

Density Surface Modeling

Data Processing

Pheasant observations were separated into eight strata by year and season. Transects were subdivided into three identical 1.6 km^2 square segments and observations were aggregated by segment (Miller et al. 2013).

Fitting a detection function

Distance sampling assumes: (1) animals are distributed independently of the lines or points; (2) objects on the line or at the point are detected with certainty; (3) distance measurements are exact; (4) objects are detected at their initial location (Buckland et al. 2015). The distance sampling detection function corrects for imperfect detection and the decreasing probability of detecting an individual with increasing distance from the survey point (Buckland et al. 1993). We used multi-covariate distance sampling to estimate a probability of detection function for pheasants in our study area and to estimate abundance within segments. We compared half-normal and hazard-rate detection functions using Akaike's Information Criterion (AIC) (Burnham and Andersen 2002, Winiarski et al. 2013, 2014, Fifield et al. 2017). We considered sex and group size stratified by season as observation-level covariates within each detection function. Adjustment terms were included only when observation-level covariates were either not available or not included. The best detection function model was verified for goodness of fit using Kolmogorov-Smirnov and Cramer-von Mises tests (Buckland et al. 2015). Goodness of fit tests examined deviations from the line x=y on the quantile-quantile plot (Miller et al. 2019).

Generalized additive model

We created generalized additive models (GAM) to estimate abundance from the detection model as a function of remotely sensed covariates generated in ArcGIS Pro version 2.4.3 (Miller et al. 2013, Winiarski et al. 2013, 2014, Fifield et al. 2017, ESRI Inc 2019). For each survey period, we averaged and assigned first order mean and second order contrast image texture values within 1.6 km^2 grids of each survey in ArcGIS Pro. We calculated proportion of wetland, non-CRP grassland, CRP grassland, developed land, row-crops agriculture, small-grain agriculture, and forest landscapes within each 1.6 km^2 survey grid in Fragstats. We then inferred relationships between abundance values within each survey grid and landscape covariates (Miller et al. 2013, R Core Team 2019).

The full GAM was fit with quassi-Poisson, negative binomial, and Tweedie response distributions (Fifield et al. 2017). The quasi-Poisson response distribution with a restricted maximum likelihood smoothing parameter provided the best fit and was used in further modeling. We fit GAMs in Program R version 1.2 (Miller et al. 2013, R Core Team 2019).

We used a combination of deviance explained, adjusted-R^2, and confidence intervals for model selection criteria (Winiarski et al. 2013). After model selection, we verified model goodness of fit and adequate flexibility of smoothing terms using simple residual plots and convergence of the smoothness selection optimization (Miller 2015, R Core Team 2019). Additionally, we assessed residual autocorrelation for each survey period using plotted correlations in the residuals at lags of 1-6 consecutive segments (Winiarski et al. 2013, Miller 2015, Fifield et al. 2017, R Core Team 2019).

We ran a sensitivity analysis by comparing abundance estimates from reduced models to the full model (Fifield et al. 2017). If the 95% confidence intervals for abundance estimates overlapped, then we determined that models were insensitive to bias from parameters.

Distribution Estimation

We created a series of 1.6 km^2 prediction grid cells over the study region in ArcGIS Pro (ESRI Inc 2019). For each survey period, we averaged and assigned first order mean and second order contrast image texture values to each prediction grid in ArcGIS Pro. We calculated proportion of wetland, non-CRP grassland, CRP grassland, developed land, row-crops agriculture, small-grain agriculture, and forest landscapes within each prediction grid in Fragstats. We then predicted abundance values within each grid based on the most supported GAM and summed values over each grid for an overall abundance

(Miller et al. 2013, R Core Team 2019). We estimated the variance of abundance estimations using the GAM uncertainty approach (Miller et al. 2013, R Core Team 2019).

RESULTS

We recorded 568 pheasant observations with higher detections occurring during winter (*n* = 152) and spring (*n* = 249) and lower detections occurring during summer (*n* = 97) and fall (*n* = 70).

Fitting a detection function

The half-normal detection function with the season covariate was selected over the hazard-rate function (ΔAIC = 26.04) and was verified using Cramér-von Mises (p-value = 0.18) and Komogorov-Smirnov (p-value = 0.06) goodness of fit tests signifying that the sample distribution does not significantly differ from the actual distribution.

Remotely sensed covariates

Many first order mean texture metrics were correlated with corresponding second order contrast texture metrics. We elected to use first order mean texture metrics in subsequent models since it is easier to interpret and had a higher deviance explained compared to second order contrast. The developed texture metric was highly correlated with multiple variables (r > |0.73|) and was removed. Row-crop, non-CRP grassland, and wetland texture metrics were correlated (r > |0.63|) and we only included wetland in distribution models. We elected to keep wetland texture metrics because of their biological importance to overwinter pheasant ecology. Finally, the proportion of non-CRP grassland was highly correlated with the proportion of row-crop agriculture and was removed prior to model development (r > |0.82|). We elected to keep row-crop agriculture because this landscape type is dominant throughout the study region and has important implications regarding foraging opportunities.

Density surface model

A quasi-Poisson response distribution provided the best fit to the data and was used in all the generated models. The most parsimonious model included landscape composition (land cover), intra-annual vegetation differences (first-order mean texture metric), and perennial vegetation quality (NDVI). Specifically, the model predicted that pheasant abundance was positively associated with proportion of CRP grasslands, wetland availability, perennial herbaceous cover, and 30-40% row-crop agriculture (Table 1-2; Fig. 1-2). Pheasant abundance was negatively associated with proportion of forest, and < 30% proportion of row-crops (Table 1-2; Fig. 1-2).

The wetland first-order texture metric represented temporal variability in wetland phenology with higher NDVI values (more greenness) occurring during productive growing periods which coincide with increased photosynthetic activity (Pettorelli et al. 2011). Cattail productivity is associated with NDVI values >0.20, when weather warms, and runoff occurs beginning in April (Svedarsky et al. 2016). In late fall when cattails become dormant, NDVI values are ≤0.20 (Svedarsky et al. 2016). Pheasant abundance increased when wetland NDVI was ≤0.20, which suggests that pheasants strongly associated with wetlands during dormant periods and not during productive growth (Fig. 1-3).

Overall, this model explained 47% of the total deviance (Table 1-1), exhibited no autocorrelation among covariates, and the smoothing terms were verified (Table 1-2).

The estimated number of pheasants in the study region was 54,130 (95% CI: 37,718–77,683; Fig. 1-4). The sensitivity analysis demonstrated that abundance estimates were insensitive to model terms based on overlap among all estimated confidence intervals (Fig. 1-5).

DISCUSSION

In ephemeral landscapes, intra-annual landscape differences drive temporal changes in pheasant space use. As landscape differences occur, ecological requirements for pheasants also change between nesting, brood rearing, and winter life stages. By accounting for temporal variability in our model, we detected the seasonal variation in the importance of dormant wetlands in pheasant abundance. We found that pheasant abundance increased with availability of dormant wetlands during winter. Dormant wetlands likely provide concealment and structural resiliency against inclement weather. The presence of winter cover is considered an essential habitat component in South Dakota management, indicating that dormant wetlands are particularly important to pheasant ecology (South Dakota Department of Game, Fish 2016). Previous pheasant distribution models failed to capture the importance of wetlands, likely because models were parameterized with data collected during breeding, nesting, or brood rearing, and disregarded ecological requirements during winter or intra-annual landscape variation (Terry Z Riley 1995, Nusser et al. 2004, Haroldson et al. 2006, Giudice and Haroldson 2007, Nielson et al. 2008, Jorgensen 2012, Pabian et al. 2015). Underestimating the importance of winter cover could negatively impact management strategies and pheasant abundance. Lacking a single landscape element that is important within each life stage could disrupt equilibrium and limit population growth.

Pheasant management provides habitat for nesting, brood rearing, winter cover, and winter food. Previous research has documented pheasants using woody features as winter cover when wetlands are sparse or become inundated with snow (Perkins et al. 1997, Gabbert et al. 1999). Consequently, winter habitat management includes establishing both wetland and woody cover through cost-share programs in an effort to increase pheasant survival (South Dakota Department of Game, Fish 2016). However, our results demonstrated that while dormant wetlands increased abundance, woody cover decreased abundance. Therefore, implementing woody cover as winter habitat may have a net-negative effect on pheasant abundance. Instead, management efforts should prioritize emergent wetland conservation and restoration as ideal winter cover since dormant wetlands increased abundance, presumably by providing adequate thermal cover and shelter (Trautman 1982, Schneider 1985).

The critical importance of CRP grasslands intermixed with row-crop agriculture on pheasant abundance has been well documented (T. Z. Riley 1995, Haroldson et al. 2006, Nielson et al. 2008, Jorgensen et al. 2014, Pabian et al. 2015). Our results indicated that pheasant abundance increased with the amount of CRP grassland and increased with 30–40% agriculture on the landscape. Additionally, while CRP grasslands increased abundance, pheasant abundances were lower in non-CRP grasslands. Presumably, herbaceous vegetation within pastures often lack the density and vertical structure required for concealment, nesting, and brood rearing (Winter et al. 2005), whereas CRP grasslands provided high quality nesting and brood-rearing habitat (Matthews et al. 2012, Geaumont et al. 2017, Taylor et al. 2018). Row-crop agriculture provides forage that is particularly valuable during winter (Bogenschutz et al. 1995). Agriculture exceeding 40%

of an area had an asymptotic relationship on pheasant abundance. Although areas with >40% agriculture had no effect on pheasant abundance, excessive agriculture likely displaces other landscapes beneficial to nesting, brood rearing, and overwinter cover. In agricultural dominant landscapes without adequate CRP grasslands and wetland areas, pheasant abundance may be greatly reduced.

In eastern South Dakota, landscape trends since 2008 include broad-scale conversion of CRP grasslands or wetlands to agriculture (Johnston 2013, Wright and Wimberly 2013, Wimberly et al. 2017). Economic incentives for agriculture currently outcompete conservation incentives resulting in forecasted annual losses of grasslands (-5.20%) and wetlands (-0.03%) (Johnston 2013, Wright and Wimberly 2013). Diminishing complex landscape mosaics including CRP grasslands and wetlands cause fragmentation and loss of connectivity for many wildlife populations (With and Crist 1995), driving the need for improving comprehensive management policies for conservation.

Since 1933, the farm bill has delivered successful widespread conservation, but often impedes conservation delivery due to its complexity (McConnell 2019). Additionally, general enrollment allocated for CRP fails to meet demands further limiting conservation implementation in South Dakota (St. Pierre 2019). Farm bill policies including increased CRP enrollment caps, higher conservation incentives, and enforcement of conservation compliance to receive USDA program benefits are essential. However, innovative conservation opportunities outside of farm bill policies can supplement conservation efforts (McConnell 2019). For example, precision agriculture maximizes agricultural profitability by identifying and improving low-yield regions.

Low-quality regions present a conservation opportunity by establishing herbaceous buffers including perennial cool season grasses and forbs, which stabilize soil-quality thereby increasing economic profitability (St. Pierre 2019). Perennial vegetation in low-quality areas provide conservation buffers that increase abundance of grassland birds while maintaining crop production (McConnell and Burger 2016). Pheasants Forever has adopted precision agriculture practices into agricultural conservation, but state wildlife agencies could help further achieve landscape-level conservation (McConnell 2019). Pheasants Forever has conserved 4,000 acres of low-yield agriculture in South Dakota, but low-quality saline soils represent 8.3 million acres of conservation opportunity in South Dakota (St. Pierre 2019). Much of this opportunistic area may also qualify for working lands conservation programs. Considering forecasted trends of increasing agricultural practices, working lands conservation and precision agriculture could greatly improve conservation adoption. Innovative solutions of sustainable agriculture implemented across agencies could address millions of acres of environmentally sensitive areas and provide important pheasant habitat.

MANAGEMENT IMPLICATIONS

Landscape mosaics encompassing CRP grasslands and wetlands, intermixed with 30-40% agriculture, without woody cover support higher pheasant abundances. Current management practices provide ‘three-legged stool’ management consisting of nesting/brooding habitat, winter cover, and winter food (South Dakota Department of Game, Fish 2016). Our model supports the ‘three-legged stool’ approach, with CRP grasslands providing nesting/brooding habitat, wetlands providing winter cover, and agriculture providing winter forage. Traditionally, winter cover management also included shelterbelt implementation. We recommend that winter cover management prioritize wetland conservation or restoration as preferred winter habitat and implement shelterbelt as a secondary measure when wetlands are not viable.

Land use trends in South Dakota since 2008 suggest that agriculture conversion will further reduce CRP grasslands and wetlands. Therefore, conservation efforts increasing CRP grasslands and wetlands are critically important. Since agriculture is economically important in South Dakota, it is unlikely that conservation efforts can outcompete agricultural landscape conversion. To supplement conservation, integration between agriculture and conservation may have better reception and success among the community. Innovative conservation efforts addressing environmentally sensitive areas in agriculture can supplement current conservation programs. Working lands conservation incentives and precision agriculture practices across South Dakota target low-quality soils and establish perennial cover to improve soil health thus increasing native vegetation. Low-quality saline soils in South Dakota represent 8.3 million acres of environmental sensitive conservation opportunity. Integrative conservation could increase landscape mosaics that allow pheasants to thrive while maintaining economic opportunities.

Avian biodiversity has improved with the adoption of alternate farming practices (Chamberlain 2010), including sustainable and organic agriculture which has grown in popularity since the 1950's and 1980's, respectively (Lockeretz 2007). Environmental sustainability in agriculture provides stewardship to natural resources by maintaining healthy soil and water while minimizing air, water, and climate pollution. Specific farming changes that occur with organic agriculture include smaller tracts of farmland, elimination of synthetic chemicals (e.g. herbicide, pesticide, fertilizer), and crop diversification (Midwest Pheasant Study Group 2013) resulting in greater perennial cover and interspersions of agriculture and native landscapes. Encouraging increased opportunities of organic agriculture concurrently with sustainable farming practices for biodiversity and improved nesting/brooding and winter cover for pheasants should be considered.

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Table 1-1. Generalized additive models predicting pheasant abundance as a function of combinations of landscape composition, intra-annual landscape changes, or within-landscape differences in Beadle County, SD, 2017–2019. The most parsimonious model was selected using deviance explained, adjusted R^2 values, and confidence intervals.

Model	**Description**	**Deviance Explained**	**R^2 Adj.**	**Abundance (95% CI)**
Proportion crops + proportion forest + proportion CRP grassland + proportion row-crops + proportion of small-grains + proportion of wetland + $\text{CRP}_{(\text{mean})}$ + $\text{forest}_{(\text{mean})}$, $\text{wetland}_{(\text{mean})}$ + $\text{small-grain}_{(\text{mean})}$ + interaction of perennial cover and NDVI	Model includes landscape composition, intra-annual landscape changes represented by Normalized Difference Vegetation Index (NDVI) first order ‘mean’ texture metrics, and within-landscape differences represented by the interaction between perennial cover and NDVI	47.2	0.32	54,130 (37,718-77,683)
$\text{CRP}_{(\text{mean})}$ + $\text{forest}_{(\text{mean})}$, $\text{wetland}_{(\text{mean})}$ + $\text{small-grain}_{(\text{mean})}$ + interaction of perennial cover and NDVI	Model includes intra-annual landscape changes represented by Normalized Difference Vegetation Index (NDVI) first order ‘mean’ texture metrics, and within-landscape differences represented by the interaction between perennial cover and NDVI	39.04	0.21	37,718 (26,670-53,342)
Proportion crops + proportion forest + proportion CRP grassland + proportion row-crops + proportion of small-grains + proportion of wetland	Model includes landscape composition	37.72	0.18	63,495 (48,660-82,852)
$\text{CRP}_{(\text{contrast})}$ + $\text{forest}_{(\text{contrast})}$, $\text{wetland}_{(\text{contrast})}$ + $\text{small-grain}_{(\text{contrast})}$ + interaction of perennial cover and NDVI	Model includes intra-annual landscape changes represented by Normalized Difference Vegetation Index (NDVI) second order ‘contrast’ texture metrics, and within-landscape differences represented by the interaction between perennial cover and NDVI	34.5	0.16	41,874 (31,349-55,933)
Null		31.24	0.14	47,709 (39,008-58,351)

Note: All models included a quasi-Poisson response distribution, location terms, and smoothing terms.

Table 1-2. Evaluation Generalized Additive Model parameters and smoothing terms for the most parsimonious model predicting pheasant abundance as a function of landscape composition, intra-annual landscape changes, and within-landscape differences in Beadle County, South Dakota, 2017–2019.

Model	**Parameter**	**Parameter significance**		**Significance of smoothing terms**			
		F	**p-value**	**k'**	**edf**	**k-index**	**p-value**
Location + proportion (CRP) grassland + proportion developed + proportion forest + proportion row-crop + proportion small-grain + proportion wetlands + CRP$_{(mean)}$ + forest$_{(mean)}$ + small-grain$_{(mean)}$ + wetland$_{(mean)}$ + perennial cover*(NDVI)	Location	5.1	1.86e^{-14}	29.0	23.0	1.00	0.96
	CRP	18.8	1.70e^{-05}	9.0	1.0	0.92	0.41
	Developed	1.5	0.22	9.0	1.0	0.96	0.78
	Forest	6.3	0.01	9.0	1.0	0.91	0.32
	Row-crop	4.6	1.78e^{-04}	9.0	5.2	0.94	0.59
	Small-grain	0.4	0.53	9.0	1.0	0.94	0.60
	Wetland	0.7	0.54	9.0	1.6	0.95	0.60
	CRP$_{(mean)}$	0.9	0.36	9.0	1.0	0.91	0.26
	Forest$_{(mean)}$	1.3	0.25	9.0	1.0	0.91	0.26
	Small-grain$_{(mean)}$	1.3	0.28	9.0	1.7	0.90	0.26
	Wetland$_{(mean)}$	4.0	5.38e^{-04}	9.0	5.1	0.96	0.71
	Perennial cover*NDVI	2.9	7.63e^{-03}	9.0	5.4	0.97	0.82

Note: Model included landscape composition, intra-annual landscape changes, and within-landscape differences. Variables were analyzed within 1.6 km^2 of each survey and included the survey **location** to account for spatial autocorrelation. Landscape cover included proportions of Conservation Reserve Program (**CRP**) grassland, **developed** lands (i.e. roads, structures), **row-crop** agriculture, **small-grain** agriculture (i.e. winter wheat, spring wheat, durum, barley, oats, winter rye, millet), and wetlands. Intra-annual landscape changes included Normalized Difference Vegetation Index (NDVI) first order 'mean' texture metrics of **CRP$_{(mean)}$, forest$_{(mean)}$, small-grains$_{(mean)}$**, and **wetland$_{(mean)}$**. Within-landscape differences were represented by the interaction between perennial cover and NDVI.

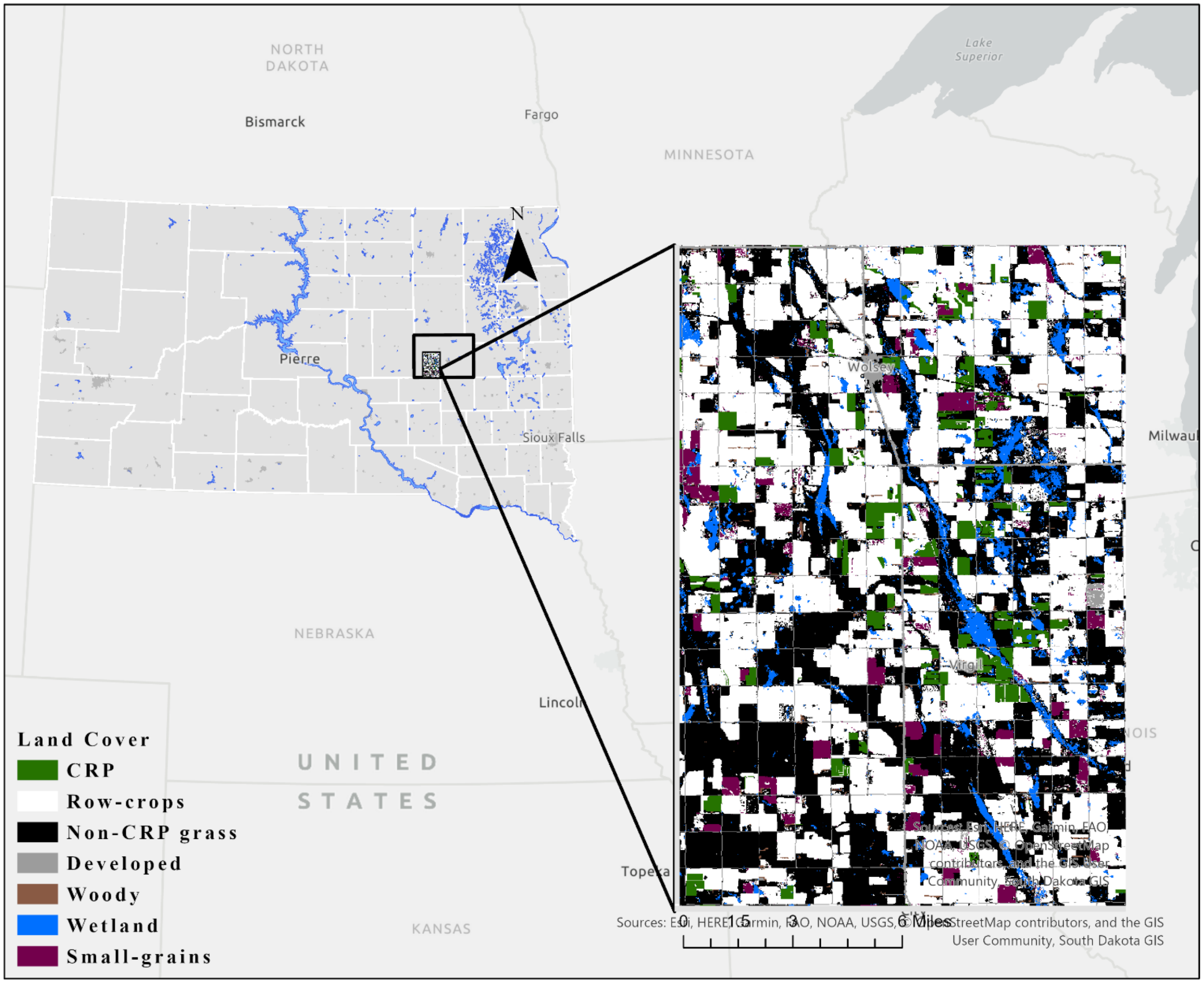

Figure 1-1. Study region for understanding ring-necked pheasant distribution in southwestern Beadle County, South Dakota, 2017–2019.

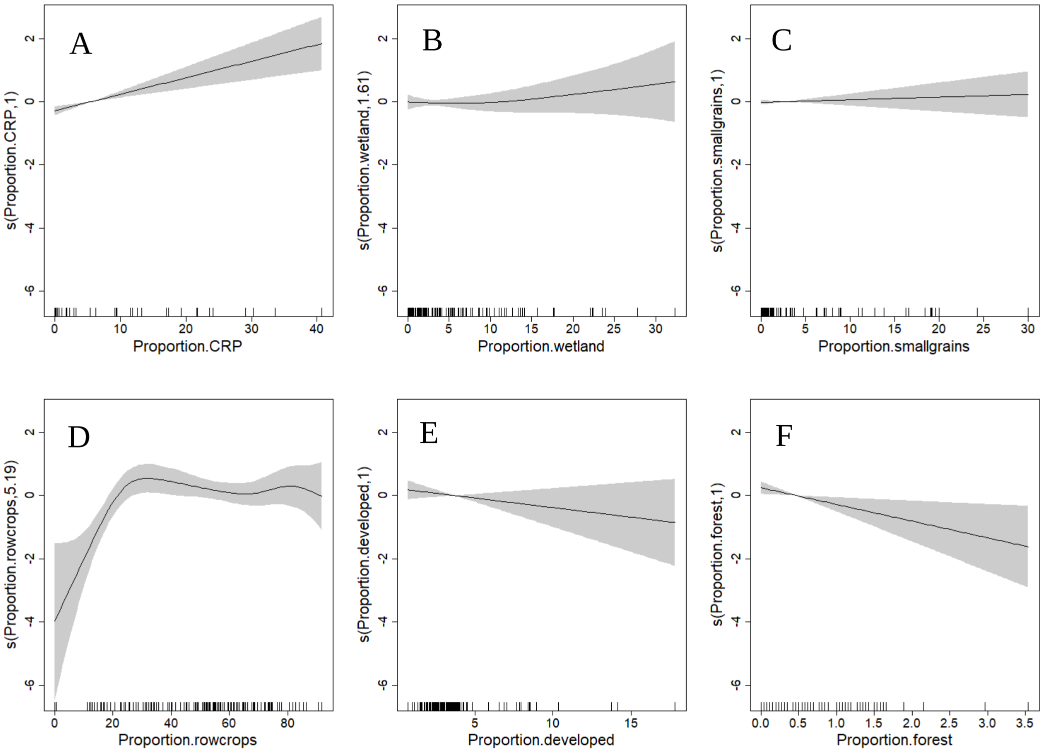

Figure 1-2. Smooth functions and 95% confidence intervals from the pheasant distribution model estimating pheasant abundance: (A) proportion of landscape enrolled in CRP (B) proportion of the landscape that are designated as wetlands (C) proportion of the landscape that is under small-grain cultivation (D) proportion of the landscape that is under small-grain cultivation (E) proportion of the landscape that is developed and (F) proportion of the landscape that is designated as forest within 1.6 km^2. The x-axis is percent of landscape within 1.6 km^2 with data distribution represented as internal tick marks. The y-axis is the log normal predicted response from the GAM output and bracketed numbers are the effective degrees of freedom of the smooth term. Log normal values and upper confidence interval <1 indicates negative influence on abundance, log normal values and lower confidence interval >1 indicates positive influence on abundance, and a selection ratio overlapping 1 indicates landscape indifference.

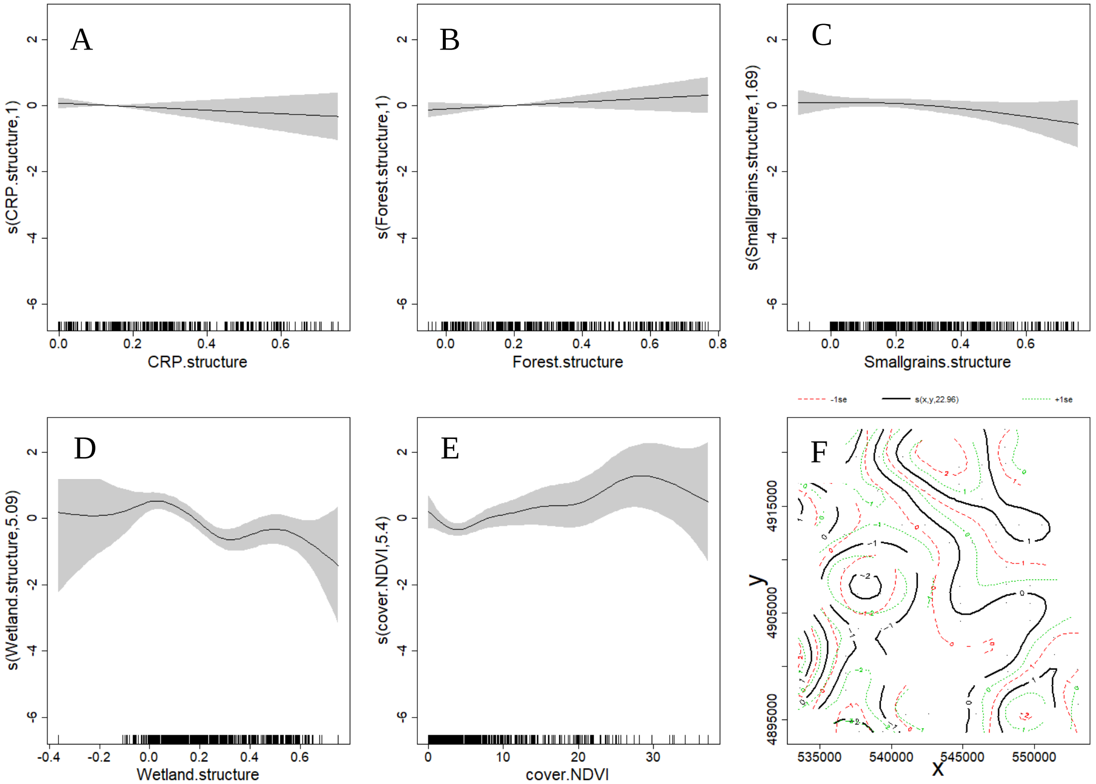

Figure 1-3. Smooth functions and 95% confidence intervals from the pheasant distribution model estimating pheasant abundance: (A) variation within CRP (B) variation within forest (C) variation within small-grain (D) variation within wetlands (E) productivity of perennial cover (non-CRP grassland, CRP grassland, wetland) and (F) location within 1.6 km^2. The x-axis is degree of intra-annual variation or productivity within 1.6 km^2 with data distribution represented as internal tick marks. The y-axis is the log normal predicted response from the GAM output and bracketed numbers are the effective degrees of freedom of the smooth term. Log normal values and upper confidence interval <1 indicates negative influence on abundance, log normal values and lower confidence interval >1 indicates positive influence on abundance, and a selection ratio overlapping 1 indicates landscape indifference.

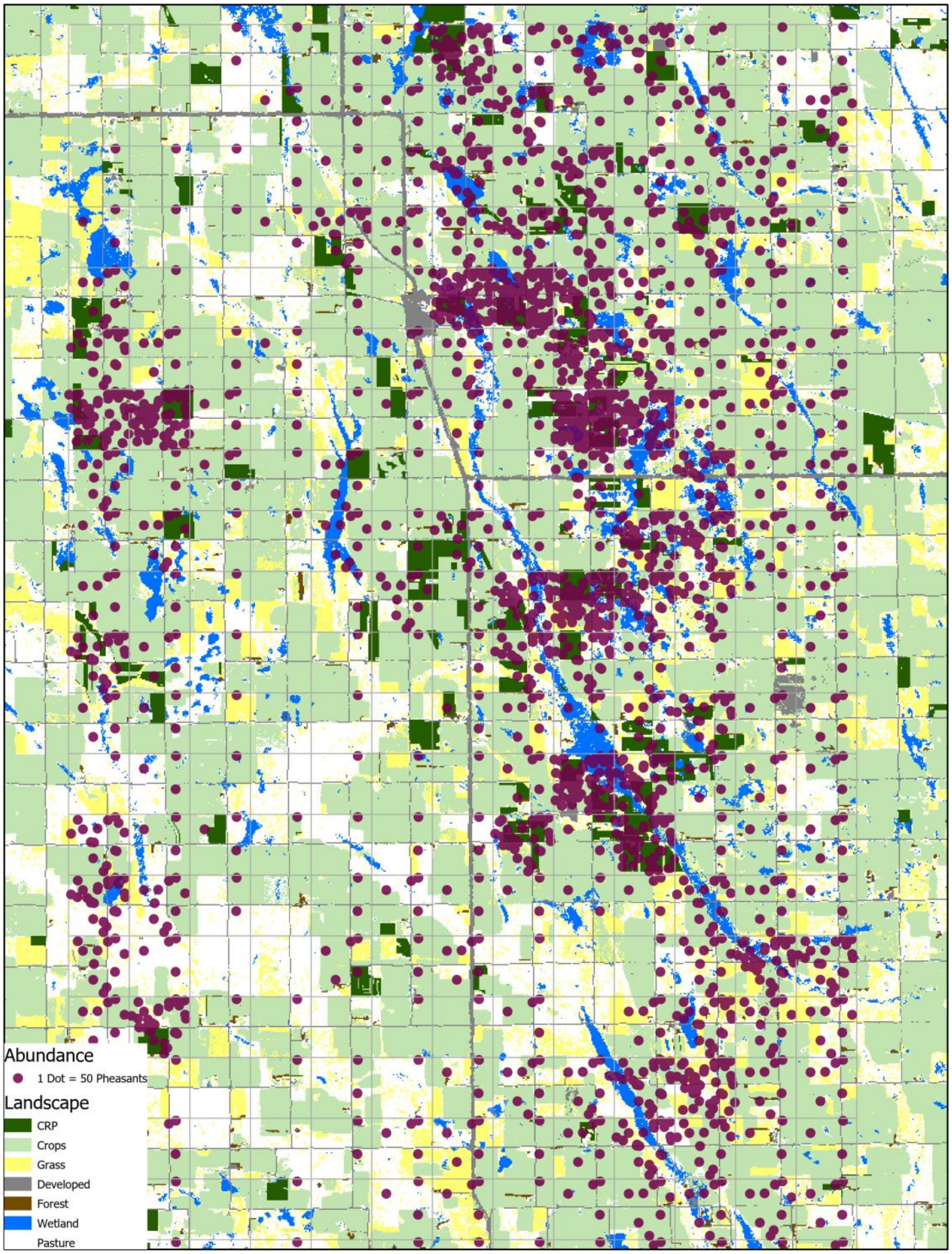

Figure 1-4. Species distribution map of pheasants as a function of landscape composition, within-habitat heterogeneity, and intra-annual landscape changes in SW Beadle County, SD, August 2018.

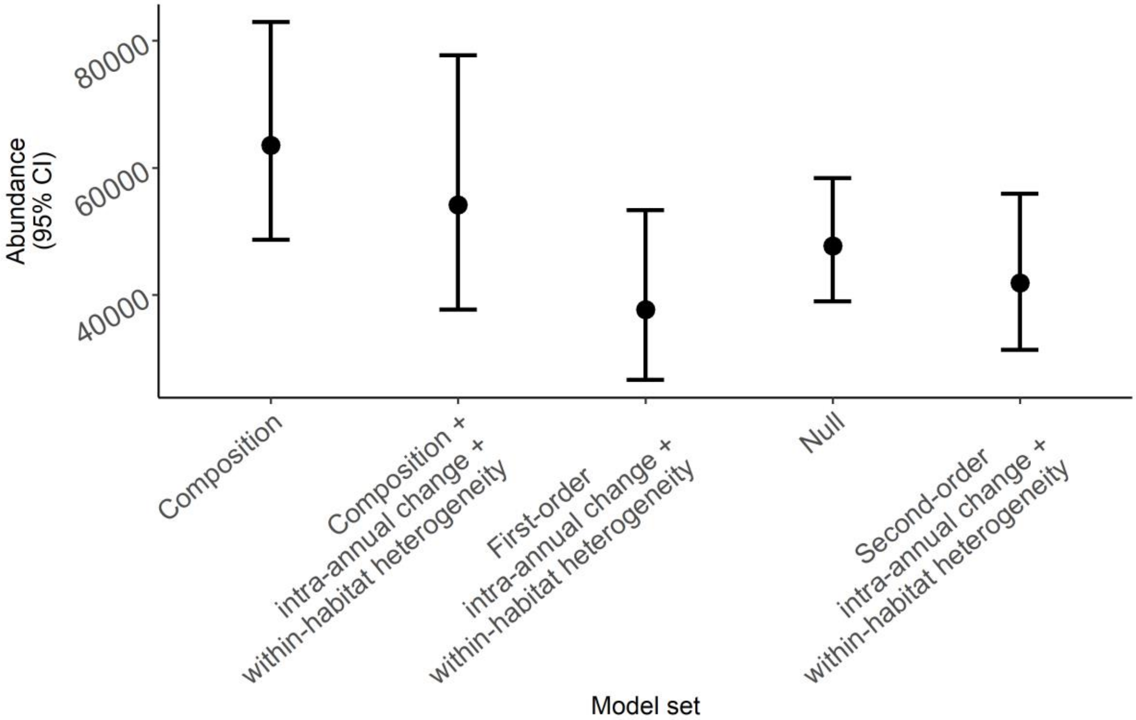

Figure 1-5. Sensitivity analysis of generalized additive models of pheasant abundance as a function of landscape composition, within-habitat heterogeneity, and intra-annual landscape changes in Beadle County, SD, 2017-2019. Landscape cover included proportions of Conservation Reserve Program (CRP) grassland, developed lands (i.e. roads, structures), row-crop agriculture, small-grain agriculture (i.e. winter wheat, spring wheat, durum, barley, oats, winter rye, millet), and wetlands. Intra-annual landscape changes represented Normalized Difference Vegetation Index (NDVI) second order 'contrast' or first order 'mean' texture metrics of landscape cover types. Within-landscape differences represent the interaction between perennial cover and NDVI.

CHAPTER 2: SNOW AND EXPOSURE IMPACT PHEASANT SURVIVAL DURING WINTER IN SOUTH DAKOTA

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ABSTRACT

Winter mortality limits Winter mortality limits ring-necked pheasant (*Phasianus colchicus*) population growth with notable adult mortality occurring during harsh winters in the Prairie Pothole Region. Recent landscape transformations could further impact overwinter adult female survival by reducing critical overwinter landscape features. Assessing the influence of landscape as a time-dependent factor on survival at small focal scales may reveal spatial relationships between pheasants and landscape features. We captured and monitored 321 adult female pheasants during the study and recorded 110 pheasant mortalities. We analyzed resource selection ratios to understand landscape preference. Pheasants exhibited positive selection for emergent wetlands, no preference for woody features, and avoidance of tall vegetation during severe winters. Pheasant winter survival was 0.66 and was highly influenced by snow depth. We generated cox-proportional hazard models to determine risk of mortality associated with landscape features. Pheasants using harvested fields experienced a 421% increased risk of raptor predation than pheasants actively using concealment. Additionally, pheasants experience a 58% lowered risk of weather mortality when using emergent wetlands. Pheasants would greatly benefit from implementation of emergent wetlands and widely available concealed foraging resources.

INTRODUCTION

The Prairie Pothole Region, extending from Iowa to Canada, historically embodied a mosaic of contiguous wetlands and grasslands (Naugle et al. 2001). Early farming practices created ideal interspersions of agriculture and native landscapes that allowed ring-necked pheasants (*Phasianus colchicus*; hereafter pheasants) to thrive (Taylor et al.

2018). Recently, the Prairie Pothole ecosystem has undergone rapid agro-economic expansion effectively reducing ideal interspersions of native prairie and cropland into agriculturally homogeneous landscapes (USGAO 2007, Wright and Wimberly 2013, Wimberly et al. 2017). Furthermore, rapid widespread landscape transformations are projected to continue as Conservation Reserve Program (CRP) contracts expire and commodity prices associated with agricultural crops remain high (Wright and Wimberly 2013). In South Dakota, over one million acres of grassland were converted into agricultural production between 2006-2012 (Reitsma et al. 2014). Additionally, only 10% of historic wetlands remain in eastern South Dakota, Minnesota, and Iowa and face ongoing declines of ~0.3% per year due to agricultural drainage (Johnson et al. 2005, Johnston 2013). Rapid agro-economic expansion creates landscape fragmentation and alters wildlife dispersal, distribution, stability, abundance, and persistence (Saunders et al. 1991, With and Crist 1995).

Since the successful establishment of pheasants to South Dakota in 1908, populations have been highly variable with years of high abundances documented in the 1930s, 1940s, early 1960s, and late 2000s. High abundances coincided with periods of idle agriculture occurring during the Great Depression and World War II and during successful land retirement programs including the Soil Bank Program and the CRP. Pheasants thrive with complex landscapes encompassing grassland blocks, overwinter cover, and food resources within their home range (Clark et al. 1999, Taylor et al. 2018). Pheasants use herbaceous vegetation as nesting and brood-rearing cover, emergent wetlands or woody features for overwinter shelter, and agricultural waste grain as winter forage (Bogenschutz et al. 1995, Clark et al. 1999, Gabbert et al. 1999, Taylor et al.

2018). Recently, pheasant abundance indices suggest persistent population declines since 2008, raising concerns regarding landscape viability. Grassland conversion paired with emergent wetland depletion could have negative implications for nesting, brood rearing, overwinter life stages, or overall pheasant population longevity.

Although chick survival is the factor predominantly hypothesized to limit pheasant population growth (Clark et al. 2008), winter mortality of adults also limits population growth with notable mortality occurring during harsh winters in the Prairie Pothole Region in 1993-1994 and 1996-1997 (Perkins et al. 1997, Gabbert et al. 1999, Clark et al. 2008). Adult female pheasant (hereafter hen) winter mortality reduces potential breeding and nesting populations (Trautman 1982), impacting overall population dynamics and limiting population growth. As snow depths increase during the winter, many individuals succumb to starvation, suffocation or increased vulnerability to predation (Farris et al. 1977, Trautman 1982, Gabbert et al. 1999, Flake et al. 2012). Recent landscape transformations could further impact overwinter survival of hens by reducing critical overwinter landscapes. Hen survival during winter is imperative to population stability (Clark et al. 2008).

Research has shown that pheasants use emergent wetlands and grasslands under mild conditions and further select emergent wetlands, food plots, and woody features as snow accumulates and temperatures decline (Perkins et al. 1997, Gabbert et al. 1999). Pheasants seek emergent vegetation, warm-season grasses, and woody features (i.e. linear stands of low-growing trees and shrubs) presumably for thermal or protective cover (Fedeler 1973, Olson 1975, Trautman 1982, Craft 1986, Gabbert et al. 1999, Schilowsky 2007). Overall, typical winter probability of survival ranges from 0.60-0.95, while survival declines to 0.03-0.45 in severe winters (Perkins et al. 1997, Gabbert et al. 1999, Homan et al. 2000). Past studies have associated food plot use with increased survival, but have not shown cropland, grassland, or wetland landscapes to have significant influence on winter survival of pheasants at home range or large spatial scales (Perkins et al. 1997, Gabbert et al. 1999, Homan et al. 2000). Assessing the influence of landscape as a time-dependent factor at smaller focal scales may better represent spatial relationships between pheasants and landscape use. A better understanding of the functional link between landscape use and risk of mortality would increase our understanding of pheasant survival.

Agriculturally dominated landscapes paired with weather severity may pose challenges to finding adequate protective residual cover during winter, often leading to increased exposure. Subsequently, increased exposure results in increased predation, which is well documented as the primary cause of pheasant mortality during winter (Dumke and Pils 1973, Perkins et al. 1997, Riley and Schulz 2001). Furthermore, linear edges and artificial perches (i.e. powerlines, fences, trees) are common throughout agricultural landscapes and improve hunting efficiency of mammalian and avian predators (Marini et al. 1995, Agriculture 1996). Additionally, the abundance of medium-sized mammalian predator populations may increase in conjunction with landscape changes, human development, and suppression of large predators (Prugh et al. 2009, Greenspan et al. 2018). Since pheasants are vulnerable to both avian and mammalian predation, identifying cause-specific mortality risk of landscape features or landscape use is critical to effectively managing landscapes and alleviating predation pressure.

An assessment of the influence of landscapes on hen survival, mortality risk, and resource selection during winter is useful to wildlife managers. The objectives of this study included: (1) determine winter resource selection of hen pheasants; (2) model cause-specific mortality risk of landscape use; and (3) estimate hen overwinter probability of survival and model environmental factors influencing survival. From our research, we predicted that overwinter hen survival would decrease with inclement environmental conditions. Secondly, we expected that decreased cover opportunities would increase cause-specific mortality risk.

STUDY AREA

The study region covered a 270 km^2 area of southwestern Beadle County in eastern South Dakota, United States (Fig. 2-1). Beadle County experiences arctic air surges during the winter, which resulted in 20-year average temperatures of -1.5° C (January-April) (National Oceanic and Atmospheric Administration (NOAA); http://www.noaa.gov/). Average 20-year minimum and maximum winter temperatures were -7.3° C and 4.0° C, respectively (NOAA). Average 20-year snow depth was 7.0 cm (NOAA). The Beadle County landscape was 53% agriculture, 30% pasture, 9% herbaceous grassland (i.e. CRP, waterfowl production areas, game production areas, walk-in areas), 4% wetland, 4% developed, and <1% woody features (CropScape; http://nassgeodata.gmu.edu/CropScape/).

METHODS

Capture & Monitoring

Hens were captured from December to March using walk-in traps baited with corn (*Zea mays*) (Wilbur 1967). Traps were checked in the morning and evening to minimize hen exposure time. Hens were also captured with night spotlighting during September and April (Labisky 1968). During spotlighting, pheasants were identified by subtle vegetation movement in tallgrass landscapes using nocturnal spotlights, led headlamps, and LED light bars mounted on UTVs and were captured using long-handled conservation nets (Frabill, Plano IL, USA). Supplemental captures increased sample sizes during early winter when bait-trapping was insufficient due to limited snow cover resulting in widely available food resources for pheasants. Captured hens were fitted with either a 15-gram very-high frequency (VHF) necklace style, 25-gram global positioning system (GPS) necklace style, or a 42-gram GPS and VHF combination backpack style transmitter equipped with mortality sensors that triggered after six hours of inactivity (Advanced Telemetry Systems, Isanti MN, USA). Additionally, hens were weighed and banded with aluminum metal leg bands (National Band and Tag Company). All animal handling procedures followed the guidelines approved by The Ornithological Council (Fair et al. 2010) and were approved by the Institutional Animal Care and Use Committee at South Dakota State University (Approval No. 16-086A).

Windows Mobile compatible GPS unit with Locate III (Pacer Computing, Tatamagouche, NS, Canada) were used in conjunction with a null-peak truck-mounted telemetry system to assign each bird with Universal Transverse Mercator (UTM) coordinates (UTM Zone 14N, NAD 1983 Continental United States). Locations were estimated 4-5 times per week using ≥ 3 bearings with ≤ 1,500 m^2 error of ellipse across a 13-week period from January to April.

Whenever a mortality signal was detected, research personnel immediately documented the date and located the carcass or collar when possible to determine the probable cause of death. The cause of death was assigned as raptor or mammalian predation following a ‘Probable cause of death’ key (Sargeant et al. 1998). Raptors common to South Dakota during winter included bald eagle (*Haliaeetus leucocephalus*), sharp-shinned hawk (*Accipiter striatus*), northern goshawk (*Accipiter gentilis*), red-tailed hawk (*Buteo jamaicensis*), rough-legged hawk (*Buteo lagopus*), northern harrier (*Circus cyaneus*), ferruginous hawk (*Buteo regalis*), golden eagle (*Aquila chrysaetos*), gyrfalcon (*Falco rusticolus*), prairie falcon (*Falco mexicanus*), snowy owl (*Bubo scandiacus*), great horned owl (*Bubo virginianus*), barred owl (*Strix varia*), and long-eared owl (*Asio otus*). Common mesopredators in eastern South Dakota included coyote (*Canis latrans*), badger (*Taxidea taxus*), raccoon (*Procyon lotor*), red fox (*Vulpes Vulpes*), bobcat (*Lynx rufus*), and feral cat (*Felis catus*). Weather mortalities were assigned as cause of death when a carcass was found in its entirety without trauma and appeared emaciated, had frozen nostrils, or was found beneath the snow (Flake et al. 2012). Mortalities that were not immediately visited or had trauma without obvious signs of predation were categorized as unknown. Radio-collars that appeared to have fallen off due to a missing clamp were categorized as operator error. Capture-related mortalities (i.e., exposed cranium, extreme physical distress) and individuals that died before their initial relocation were censored from the analysis.

Landscape Mapping

Landscapes, telephone lines, and fence lines were mapped using ArcGIS Pro imagery and ground reconnaissance. Maps were then digitized into ArcGIS Pro version 2.0 (ESRI, Inc., Redlands, CA, USA). Landscapes were mapped during the winter to avoid structural change before spring and classified as harvested field, emergent wetland, tall vegetation (>75 cm), developed (i.e. roads, structures), food plot (unharvested crops), woody (i.e. linear stands of low-growing trees and shrubs), and other. Lands enrolled in CRP were identified using U.S. Department of Agriculture shapefiles at a minimum mapping unit 0.0265 ha.

Weather Severity

With slight modifications to methodology from Baccante and Woods (2010), we calculated winter weather severity index (WSI) from daily snow depth and temperature averages obtained from the nearest weather station 17 ± 4 km from the study area. The proximity of this weather station was similar to previous pheasant research in the Prairie Pothole Region and reasonably represented the climate of the study area (Gabbert 1997, Perkins et al. 1997). Daily WSI was summed across the 13-week study period (January to April) for a cumulative winter WSI (Baccante and Woods 2010). Daily WSI values were compared between years using an ANOVA test.

Resource Selection

Previous research has documented altered landscape use by pheasants depending on winter weather conditions (Perkins et al. 1997, Gabbert et al. 1999). To identify winter landscape use, we used a resource selection ratio (w_i). We calculated 95% minimum convex polygons (MCP) for individuals with ≥ 25 locations (Perkins et al. 1997).

Random ‘available’ points were created for every ‘used’ location within the corresponding MCP and landscape types associated with each used or available point were determined in ArcGIS Pro 2.0. We used a Design III Manly selection ratio of resources between used and available points. We determined that resources were used in greater proportion than available (i.e., selected for) when w_i and the lower 95% confidence interval were >1. Alternatively, we determined that resources were used less proportionally than available (i.e., avoided, or selected against) when w_i and the upper 95% confidence interval were <1 (Manly et al. 2002). When w_i and the 95% confidence interval overlapped 1, resources were used in proportion to availability (i.e., no selection).

Survival

Using Program MARK version 6.2 (White and Burnham 1999), we estimated weekly hen survival using Kaplan-Meir methods modified for staggered-entry (Kaplan and Meier 1958, Pollock et al. 1989). We modeled survival starting after the first Sunday in January over 13-weekly encounter histories in each of three years, 2017–2019. We modeled survival as a function of weekly climatic data averaged over seven days corresponding to each encounter period (Perkins et al. 1997, Homan et al. 2000). We constructed 35 models to represent potential temporal influences of year, snow depth (cm), temperature variance (°C), minimum temperature (°C), wind speed (km/h), weight (kg) and collar type (VHF, GPS, or VHF/GPS). All climatic data were obtained from the National Oceanic and Atmospheric Administration (NOAA) at the nearest location within Beadle County, approximately 25 km away. We tested for correlated variables ($r \geq |0.60|$)

(Taylor et al. 2016) and selected one of the correlated variables that made the most biological sense for subsequent models.

Mortality Risk

We used a competing risks framework to investigate the influence of landscape features on cause-specific mortality using the Andersen-Gill derivation of the cox proportional hazard rate model (Johnson et al. 2004, Murray et al. 2010, Winder et al. 2017). Andersen-Gill hazard rate models incorporate time-dependent effects of continuous or categorical variables for right- and left- censored data (Johnson et al. 2004, White et al. 2010, Winder et al. 2017).

We identified and separately modeled three competing risks: raptor predation, weather mortality, and mammalian predation. We chose to model competing risks separately because the modes of mortality could be the effect of unique landscape features. We constructed 13-weekly time intervals for each pheasant starting after the first Sunday in January for each of three years, 2017–2019. Within each interval, we assigned one location per pheasant corresponding to the last available location within that interval (Johnson et al. 2004, Winder et al. 2017). Data were structured so each relocation included day of entry, day of exit, fate, failure type, and landscape covariates (Winder et al. 2017). In each model, fate was coded as 1 for cause-specific mortality and 0 for unrelated mortality or right-censored data (Johnson et al. 2004, Winder et al. 2017). Individuals that went missing or survived the duration of the study were considered right-censored (Johnson et al. 2004, Dinkins et al. 2014, Winder et al. 2017). Individuals with staggered entry were considered left-censored (Johnson et al. 2004, Dinkins et al. 2014, Winder et al. 2017).

We selected the most supported model for each competing risk using a combination of meaningful hazard rate confidence intervals, Akaike's Information Criteria corrected for small sample size (AIC_c) and verification of model assumptions (Burnham and Andersen 2002, White et al. 2010). When models were within $\Delta AIC_c \leq 2.0$ and differed from the top model by a single parameter, predictor variables were considered uninformative when 85% hazard rate confidence intervals overlapped 1 (Johnson et al. 2004, Arnold 2010, Dinkins et al. 2014, Leroux 2019). We determined increased mortality risk when the hazard ratio was >1, indicating a positive association between a covariate and mortality rate. Alternatively, we determined decreased mortality risk when the hazard ratio was <1, indicating a negative association between a covariate and mortality rate (Johnson et al. 2004, White et al. 2010). We compared hazard rate models using standard Akaike's Information Criteria corrected for small sample size (AIC_c), the difference between the minimum AIC_c and model AIC_c (ΔAIC_c), and AIC_c weights (ω) (Burnham and Andersen 2002, Johnson et al. 2004, Murray et al. 2010, Dinkins et al. 2014, Winder et al. 2017). To assess model fit we examined Schoenfeld residuals for a uniform distribution around zero (Therneau and Grambsch 2000, Johnson et al. 2004). To verify the hazard rate model assumption of proportional hazards we plotted scaled Schoenfeld residuals against time for each variable and the global model (Therneau and Grambsch 2000, Johnson et al. 2004, Winder et al. 2017). We arcsine-transformed density metrics and square-root-transformed proximity metrics that did not meet model assumptions (White et al. 2010). We tested for correlated variables ($r \geq |0.60|$) (Taylor et al. 2016) and selected one of the correlated variables that made the most biological sense for subsequent models.

Model development

We created three independent model sets to understand landscape risk factors associated with raptor, weather, and mammalian mortality following our hypotheses: (1) mortality risk from raptor predation would be greater with available perching opportunities and reduced concealment; (2) weather-related mortality would be greater with less available thermal cover and; (3) mammalian predation would be greater in overlapping niches that include woody features or edges. We calculated proximity from used locations to anthropogenic and landscape features >2 m in height that could be used as perching opportunities for raptors including woody features, telephone lines, standalone trees, and fences (Table 2-1; Dinkins et al. 2014). We calculated proximity from used locations to available thermal cover including emergent wetlands, CRP, and woody features that were thought to impact weather mortality (Table 2-1). We calculated proximity from used locations to features including roads, edges, woody features, and fence lines often used by mesopredators (Table 2-1). Additionally, we calculated the density of woody features, roads, and emergent wetlands within four different radii of used pheasant locations (i.e., 100, 200, 300, and 400 m radii) (Dinkins et al. 2014).

In addition to modelling juxtaposed landscape features that may impact pheasant mortality, we extracted actively used land cover. We created six sets of landscape use models categorized into biological relevant land-cover classifications. Since the impact of landscape use on pheasant mortality is unknown, we tested different land-cover categorizations that reflected variations of potentially valuable resources (Table 2-1). We evaluated Cox proportional hazard models of land-cover classifications in an AIC_c framework separately for raptor, weather, and mammalian mortality (Dinkins et al.

2014). We selected and added the most supported landscape use model to the comprehensive models set with proximity and density metrics.

Final model development included combinations of landscape use and proximity metrics (Table 2-1). Density metrics were eliminated due to high correlation with proximity metrics. Our decision to eliminate density metrics rather than proximity metrics was driven by the desire to understand fine-scale landscape use that creates differences between life histories of multiple individuals inhabiting a single territory. Density metrics would be similar among all individuals inhabiting an area, whereas proximity metrics would likely differ and more accurately convey different life histories at a finer scale. Furthermore, density metrics may fail to adequately capture slender or narrow landscape features that proximity metrics may better characterize, such as standalone trees or posts that could exist as detrimental perching opportunities. We also wanted to avoid pseudoreplication from using a multitude of similar density metrics from many individuals inhabiting the same area. Each model was stratified by snow depth (cm) averaged over each weekly interval to account for interactions of landscape use and weather severity since this was found to be the most significant parameter in the survival model (*see Results)*.

RESULTS

We captured and monitored 321 hens during the study (2017: *n* = 87, 2018: *n* = 90, 2019: *n* = 144). We deployed a combination of VHF (*n* = 286), GPS (*n* = 23), and GPS/VHF (*n* = 12) radio transmitters. We recorded 110 pheasant mortalities resulting from raptor predation (*n* = 61), mammalian predation (*n* = 15), weather (*n* = 17), and unknown (*n* =

17; Table 2-2). Nine individuals died before a relocation event and were censored from analysis.

Weather Severity

We experienced an increase in winter weather severity with each subsequent winter (429.3 WSI, 662.9 WSI, 2425.7 WSI; Table 2-3). WSI did not differ between 2017 and 2018 ($F_2 = 3.3$, $P = 0.07$), whereas WSI during 2019 was higher than 2017 ($F_2 = 61.9$, $P \leq 0.001$) and 2018 ($F_2 = 45.4$, $P \leq 0.001$). Overall, 2019 had below average temperatures and above average snow depths while 2017 and 2018 had comparable temperatures and below average snow depths (Table 2-3).

Resource Selection

We had 88 hens with ≥ 25 locations used for resource selection ratios (2017: *n* = 0, 2018: *n* = 56, 2019: *n* = 32). Pheasants exhibited weak positive selection for residual wetlands during 2018 ($\hat{w} = 1.294$, CI = 1.093 – 1.496; Fig. 2-2) with stronger positive selection during 2019 ($\hat{w} = 2.220$, CI = 1.724 – 2.717; Fig. 2-2). We documented no selection for tall vegetation during 2018 ($\hat{w} = 1.075$, CI = 0.969 – 1.180; Fig. 2-2) and avoidance during 2019 ($\hat{w} = 0.803$. CI = 0.658 – 0.947; Fig. 2-2). We documented no selection for woody features during both winters (Fig. 2-2). Although we did not statistically account for differences between food plot selection during 2018 and 2019, there was a large shift towards positive selection in 2019. However, due to small sample size of food plot availability during our study, we cannot make specific inferences.

Survival

We considered 35 models in our probability of survival analysis (Table 2-4). The top eleven models represented >0.90 of the available model weight. The top-ranked model was the most parsimonious and included snow depth and collar type. Snow depth proved to be an important parameter as it appeared in every model with $w_i > 0.00$. Survival between collar types was 0.64 (SE = 0.03, CI = 0.57-0.71), 0.90 (SE = 0.09, CI = 0.54-0.99), and 0.35 (SE = 0.15, CI = 0.13-0.70) for VHF, GPS and VHF/GPS, respectively, however, estimates did not significantly differ from among collar types. This could indicate that collar type influenced pheasant survival, but disproportionate sample sizes limit inferences. Our results indicated an inverse relationship between snow depth and survival (Fig. 2-3). Winter survival of hens was 0.66 (SE = 0.03, CI = 0.59-0.73).

Mortality Risk

For each model, we censored individuals with unknown cause of death, individuals without relocations, and individuals that had an unacceptable tracking error of ellipses (*n* = 60). We evaluated cause-specific mortality risk for 234 hens using 1,856 observations and 60 mortality events. Initially, we considered different candidate models for each competing mortality risk with combinations of landscape use, proximity, and density covariates. However, we found high correlation between distance to emergent wetlands and emergent wetland density ($r \geq |0.84|$), distance to roads and road density ($r \geq |0.86|$), distance to woody and woody density ($r \geq |0.80|$), and distance to perch and distance to woody($r \geq |0.69|$). Therefore, we choose to run the analyses using proximity metrics instead of density metrics when the two were correlated.

Raptor-specific mortality

The landscape use models had two top competing models $\Delta AIC_c \leq 2.0$ for avian-mortality risk (Appendix 1). We elected to use the land use model including perennial cover, harvested fields, and other because there is likely an important distinction in use of harvested fields as a food resource in subsequent models including proximity variables. We considered 17 models using combinations of landscape use and proximity metrics of active pheasant locations stratified by snow depth (Table 2-1). There was one most supported model $\Delta AIC_c \leq 2.0$, which included active landscape use, distance to perch, and the interaction between landscape use and distance to perch (Table 2-1). The proportional hazards assumption was not violated for any parameter in this model. This model suggested that pheasants actively using harvested fields experienced a 421% increased risk of mortality than pheasants actively using concealment (i.e. emergent wetland, tall vegetation, woody, and food plot; Fig. 2-4). Additionally, pheasants actively using ‘other’ (i.e. short vegetation, developed, or water) experienced a 157% more risk of raptor predation than those actively using concealment (i.e. emergent wetland, tall vegetation, woody, and food plot; Fig. 2-4). The model also suggested that pheasants actively using harvested fields or ‘other’ experienced a decreased risk of mortality with increased distance to a perch (Fig. 2-4).

Weather-specific mortality

The land use models had two top competing models $\Delta AIC_c \leq 2.0$ for weather-mortality risk (Appendix 1). We elected to use the land use model including emergent wetlands and other in subsequent models including proximity variables. We considered 16 models with the combination of landscape classification and proximity metrics of active pheasant locations stratified by snow depth. There was one most supported model $\Delta AIC_c \leq 2.0$, which included active land use and distance to CRP. The proportional hazards assumption was not violated for any covariate in this model. The model suggested that pheasants experience a 58% lowered risk of weather mortality when actively using emergent wetlands than ‘other’ (tall vegetation, woody, developed, short vegetation, harvested field, food plot) landscape types (Fig. 2-4). This model also suggests a 3% decrease in mortality risk with distance to CRP (Fig. 2-4).

Mammalian-specific mortality

The land use models had one top competing model $\Delta AIC_c \leq 2.0$ for mammalian-mortality risk, which included perennial cover, harvested fields, and other landscape classifications that was used in subsequent models (Appendix 1). We considered 17 models with the combination of landscape classification and proximity metrics of active pheasant locations stratified by snow depth. Although there were two models $\Delta AIC_c \leq 2.0$, the proportional hazards assumption was violated for the top-ranked model including active land use, distance to woody, and distance to fence. After removing the model that violated assumptions, there were two models $\Delta AIC_c \leq 2.0$. We elected to use the model including active landscape use and distance to woody features because it was simpler and considered not differentiable from the top ranked model. The proportional hazards assumption was not violated for any covariate in this model and all parameters were informative. The model suggested that pheasants experience an 84% reduced risk of mammalian predation when actively using harvested fields and a 48% reduced risk when actively using concealment (i.e. cattail-wetlands, tall vegetation, woody, and food plots) than ‘other’ (i.e. short vegetation, developed, open-water) landscape types (Fig. 2-4). Additionally, the model suggests a 3% increased risk with distance to woody features (Fig. 2-4).

DISCUSSION

Snow accumulation indirectly influenced hen survival, while predation was the primary cause of mortality. Notably, raptor predation was three-times more prevalent than mammalian predation or direct weather mortality. Snow accumulation increased pheasant exposure and vulnerability leading to higher predation rates by decreasing accessibility to cover and forage. Pheasant mortality parabolically increased with snow depth, particularly when accumulations exceeded 10 cm. Consequently, providing low-risk landscapes including emergent wetlands and concealed forage opportunities that mitigate direct mortality risk under inclement winter weather should be a management priority.

Primarily, residual vegetation, cattail-wetlands, or woody features serve as overwinter cover (Gabbert 1997, Perkins et al. 1997, Homan et al. 2000). Inadequate vegetation density or height results in low-quality cover, snow inundation, or compression under immense snow, reducing overall cover availability. Limited concealment opportunities result in localized winter habitat, causing behavioral changes, concentrated groups, and increased exposure (Petersen 1979, Petersen et al. 1988, Gabbert et al. 1999, Homan et al. 2000). Petersen (1979) suggested that raptors recognize and exploit pheasant vulnerability when landscapes or conditions result in inadequate cover. Furthermore, raptor predation pressure intensifies as ‘buffer prey’ become inaccessible under accumulating snow (Petersen 1979, Petersen et al. 1988). All concealment landscapes in our study including cattail-wetlands, tall vegetation, and woody features decreased predation risk. However, resource selection and risk assessments suggested that cattail-wetlands provided superior overwinter concealment to tall vegetation and woody cover. We found that pheasants generally selected for cattail-wetlands, and selection for cattails intensified with increasing snow depth. Conversely, pheasants proportionally used woody features and avoided tall vegetation with increasing snow depths. Cattail rigidity and density reduce wind velocity, thereby reducing wind chill and energetic demands substantially better than woody features (Schneider 1985). Despite providing concealment, woody landscapes inherently increase raptor predation risk by providing perching opportunities when positioned nearby harvested fields. Therefore, benefits of woody features as concealment may be negated by potentially establishing perching opportunities. Previous research has documented pheasants using woody features as an emergency resource when cattails are sparse or become inundated with snow (Perkins et al. 1997, Gabbert et al. 1999). Consequently, there has been a recent push in South Dakota to establish woody cover through cost-share programs to increase pheasant winter survival in critical management areas (South Dakota Department of Game, Fish 2016). However, extreme inundating snow accumulation exceeding 80 cm has not been documented in the study region in recorded history of snow depth measurements (NOAA). Conditions experienced during our study were representative of typical South Dakota winters with fluctuating patterns between mild and severe conditions. More importantly, multiple studies have reiterated the critical importance of idle herbaceous landscapes as winter cover (Craft 1986, Gabbert et al. 1999, Leif 2005, Schilowsky 2007). Cattail-wetlands are selected by pheasants, act as emergency cover, and decrease mortality risk. This suggests that improving overwinter pheasant survival requires emergent wetland restoration and preservation as a stronger management action than establishing woody cover. Comprehensive pheasant management must include cattail-wetlands while woody cover should be implemented as an alternative cover in landscapes unsupportive of cattail-wetlands.

Risk of raptor predation drastically increased with pheasants actively using harvested fields. Although waste grain from harvested fields provide high-energy forage, limited concealment results in increased exposure and predation risk. Additionally, we found that perching opportunities nearby harvested field further intensified raptor predation risk. Systematic landscape uniformity in our study area created many perching opportunities adjacent to row-crop fields including power lines, fence lines, and woody features used to delineate property boundaries. Resource selection documented avoidance of harvested fields that intensified with accumulating snow. We suggest that pheasants avoid exposure in harvested fields to mitigate raptor predation resulting in reduced feeding time (Brown et al. 1999). Previous research also suggested that intensified avoidance during harsher conditions resulted from shortened feeding periods during inclement weather (Craft 1986). Increasing snow depths increased pheasant exposure and vulnerability, particularly in high-risk landscapes, resulting in decreased resource selection of harvest fields and presumably reduced foraging. ‘Ecology of Fear’ theory suggests that fearful prey sacrifice food for safety known as ‘giving-up density’ (Brown et al. 1999). Accordingly, foraging strategies should change if landscape risk was reduced. For example, Rodgers (2002) demonstrated that vegetation height and density increased pheasant abundance in post-harvest fields. Stubble presence without weed control produced a 9-fold increase in pheasant abundance compared to fields devoid of concealment (Rodgers 2002). With decreased exposure risk, pheasants allocated increased time in foraging resources. Early farming practices using four-bottom plows, small seed drills, and manual weed removal created food sources and annual cover coinciding with high pheasant abundances (Flake et al. 2012). Modern agricultural practices since 2008 have created stark landscape contrasts with ‘clean’ fields devoid of perennial vegetation (Flake et al. 2012). Addressing modern agricultural practices that result in highly exposed landscapes during winter is critical to alleviating pheasant mortality.

Increased metabolic demands of thermoregulation in winters with prolonged intervals of sub-zero temperatures impose a need for high-quality or high-quantity forage (Delane and Hayward 1975, Bogenschutz et al. 1995). Accessing forage with snow accumulation becomes energetically demanding, necessitating pheasants, to dig through snow or ice to reach forage (Baumgras 1943, Tester and Olson 1959). Additionally, snow accumulation hinders foraging efforts translating into either increased exposure locating equivalent forage or reduced forage intake. Over a prolonged period, inadequate forage can cause individuals to become stressed or emaciated as the metabolic cost of finding forage exceeds its caloric value (Britenbach et al. 1963, Dumke and Pils 1973, Gabbert 1997). Additionally, foraging resources that necessitate traveling far from winter cover will greatly increase exposure (Petersen 1979, Larsen et al. 1994, Gabbert 1997, Homan et al. 2000). We suspect that energetic demands surpassed caloric intake on our study landscape during the severe winter of 2019, as evidenced by locating several intact pheasant carcasses in emergent wetlands and grasslands that appeared to be emaciated.

Inadequate food resources impede survival in that: 1) a lack of food resources reduces the caloric availability of the landscape leading to metabolic stress, which 2) necessitates pheasants spending more time exposed to other risk factors while foraging for food, leading to 3) higher ‘giving-up densities’ in high-risk harvested fields resulting in decreased foraging effort. This creates a cyclic effect of pheasants being undernourished and vulnerable to predation during winter as snow accumulates. Our data suggested that increased availability of concealed forage opportunities could alleviate predation and undernourishment. Gabbert et al. (1997) documented selection and improved survival of pheasants with accessible food plots. The availability of food plots or concealed forage can mitigate starvation by providing reduced-risk landscapes that increase fat reserves and meet metabolic demands while decreasing exposure and vulnerability (Bogenschutz et al. 1995). We had a limited sample size of food plot availability during our study and could not adequately quantify the relationship between food plot use and pheasant mortality risk. However, even with limited inference, resource selection ratios indicated the highest food plot use during the severe winter. A better understanding of the functional link between food plot use and risk of mortality would further increase our understanding of overwinter pheasant landscape requirements. Cost-share programs promoting food plot establishments near existing winter cover could decrease mortality risk by juxtaposing concealment and forage (South Dakota Department of Game, Fish 2016).

The Prairie Pothole Region was historically a mosaic of contiguous emergent wetlands and grasslands (Naugle et al. 2001). Present-day landscape fragmentation or connectivity loss are disrupting landscape contiguity. Moreover, perpetual wetland loss (~0.3%/yr) to subsurface drainage and agricultural production, is facilitating fragmentation and overwinter resource depletion (Johnston 2013). Although conservation initiatives including conservation compliance and CRP are implemented to prevent wetland deterioration, economic incentives have driven agriculture into previously unattainable emergent wetland landscapes (Johnston 2013). Additionally, agricultural pressure paired with forecasted climate change will expedite wetland loss (Wright and Wimberly 2013). Immediate conservation actions are required to preserve and restore emergent wetlands throughout pheasant ranges. Without emergent wetland restoration and preservation, pheasants will perpetually lose critical winter concealment, thereby increasing mortality risk.

MANAGEMENT IMPLICATIONS

Ring-necked pheasants in eastern South Dakota are succumbing to massive landscape transformations resulting in grassland loss, increased monocrop agriculture, larger agricultural fields, and loss of perennial vegetation. As vulnerability increases with inclement weather, pheasants rely on low-risk landscapes consisting of concealment opportunities to reduce predation pressure or emergent wetlands to decrease weather-related mortality. Agricultural intensification increases pheasant exposure and vulnerability by converting low-risk perennial vegetation into high-risk harvested fields. We recommend that managers alleviate overwinter pheasant mortality by increasing areas with perennial vegetation and emergent wetlands.

The most successful widespread conservation of native perennial vegetation and wetlands has been implemented as farm bill policy through the Conservation Reserve Program. However, with general enrollment limitations failing to meet demands in South Dakota (St. Pierre 2019), large-scale conservation efforts to improve winter habitat are restricted. Innovative conservation opportunities outside of Conservation Reserve Program can supplement conservation efforts (McConnell 2019). For example, precision agriculture maximizes agricultural profitability by identifying and improving low-yield soils. Low-quality soils present a conservation opportunity by establishing herbaceous buffers including perennial cool season grasses and forbs, which stabilize soil-quality thereby increasing economic profitability (St. Pierre 2019). Simply not farming low-yield areas would allow perennial vegetation growth and increase agricultural revenue by reducing wasted resources (McConnell 2019). Increased concealment provided by perennial vegetation integrated into agriculture encourages pheasants to use harvested fields at reduced predation risks (Rogers 2002), which in turn increases foraging activity and fitness. Pheasants Forever has adopted precision agriculture practices into agricultural conservation, but state wildlife agencies could help achieve landscape-level conservation (McConnell 2019). Pheasants Forever has conserved 4,000 acres of agriculture, but low-quality saline soil covers 8.3 million acres of conservation opportunity in South Dakota (St. Pierre 2019). Much of this area also qualifies for conservation opportunities through working lands conservation programs including Environmental Quality Incentives Program, Conservation Stewardship Program, or Regional Conservation Partnerships Program. Aside from incorporating perennial vegetation into low-yield agricultural areas, working lands conservation programs also incentivize cover crops, which would further increase concealment on harvested fields during the winter and reduce predation risk. With agricultural practices becoming more prevalent, integrated conservation efforts could greatly improve conservation adoption. Innovative solutions of sustainable agriculture implemented across agencies could address millions of acres of environmentally sensitive areas and protect perennial vegetation and emergent wetlands that pheasants require during winter.

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Table 2-1. Andersen-Gill hazard rate models examining the risk of landscape features on three independent cause-specific mortality types for female ring-necked pheasants in southwestern Beadle County, South Dakota, 2017–2019. Final Andersen-Gill models were selected using a combination of AIC$_c$, meaningful hazard-rate confidence intervals, and verification of model assumptions.

Models*	**k**	**AIC$_c$**	**ΔAIC$_c$**	**w_t**	**LL**
Raptor risk (*n* = 37)					
Land use^a + Perch + Land use^a *Perch	5	1203.80	0.00	0.59	-596.87
Perch	1	1208.07	4.30	0.07	-603.03
Land use^a + Perch	3	1208.08	4.30	0.07	-601.03
Land use^a + Fence + Perch	4	1209.20	5.43	0.04	-600.59
Fence + Perch	2	1209.22	5.45	0.04	-602.61
Land use^a	2	1209.33	5.56	0.04	-602.66
Null	0	1209.93	6.16	0.03	-604.97
Land use^a + Perch + Edge	4	1210.06	6.29	0.03	-601.02
Land use^a + Road	3	1210.53	6.75	0.02	-602.26
Perch + Fence + Road	3	1210.95	7.17	0.02	-602.47
Land use^a + Fence	3	1211.15	7.38	0.01	-602.59
Land use^a + Edge	3	1211.20	7.42	0.01	-602.60
Perch + Fence + Edge	3	1211.22	7.45	0.01	-604.89
Fence	1	1211.78	8.01	0.01	-604.92
Edge	1	1211.84	8.06	0.01	-604.43
Land use^a + Fence + Perch + Edge + Road	6	1212.90	9.13	0.01	-600.43
Land use^a + Fence + Edge	4	1212.99	9.21	0.01	-602.48
Weather Risk (*n* = 14)					
Land use^c + CRP	2	313.54	0.00	0.75	-154.76
Emergent wetland + Woody + CRP	3	317.32	3.78	0.11	-155.64
CRP	1	319.42	5.88	0.04	-158.70
Land use^c + Fence + Emergent wetland + CRP + Edge + Road + Woody	7	320.80	7.26	0.02	-153.28
Land use^c	1	321.11	7.57	0.02	-159.55
Land use^c + Woody	2	321.18	7.64	0.02	-158.58
Land use^c + Fence	2	322.37	8.83	0.01	-159.17
Land use^c + Edge	2	322.90	9.36	0.01	-159.44
Land use^c + Emergent wetland	2	323.01	9.47	0.01	-159.49
Land use^c + Woody + Emergent wetland	3	323.12	9.58	0.01	-158.54
Land use^c + Road	2	323.13	9.59	0.01	-159.55
Land use^c + Edge + Emergent wetland	3	324.49	10.95	0.00	-159.22
Emergent wetland	1	327.46	13.92	0.00	-162.73
Woody	1	327.66	14.12	0.00	-162.82
Null	0	328.57	15.03	0.00	-164.29
Emergent wetland + Woody + Road	3	328.74	15.20	0.00	-161.35

Continued.

Table 2-1. Continued

Models*	**k**	**AIC$_c$**	**ΔAIC$_c$**	**w$_t$**	**LL**
Mammalian Risk (*n* = 9)					
Land use[a] + Woody + Fence	4	480.88	0.00	0.48	-236.43
Land use[a] + Woody + Road + Edge + Emergent wetland + CRP + Fence	8	482.27	1.40	0.24	-233.10
Land use[a] + Woody	3	483.35	2.47	0.14	-238.67
Fence + Woody	2	485.35	4.47	0.05	-240.67
Land use[a] + Fence	3	486.35	5.47	0.03	-240.17
Land use[a] *Woody + Land use[a] + Woody	5	486.59	5.71	0.03	-238.28
Land use[a] + Road	3	488.35	7.47	0.01	-241.17
Woody	1	489.13	8.25	0.01	-243.56
Land use[a]	2	489.61	8.73	0.01	-242.80
Fence	1	490.45	9.57	0.00	-244.22
Fence + Road	2	490.72	9.84	0.00	-243.36
Emergent wetland + Woody	2	490.91	10.03	0.00	-243.45
Land use[a] + Edge	3	491.60	10.72	0.00	-242.79
Land use[a] + CRP	3	491.60	10.73	0.00	-242.80
Null	0	494.83	13.96	0.00	-247.42
Emergent wetland	1	496.83	15.96	0.00	-247.42
Emergent wetland + Edge	2	498.76	17.89	0.00	-247.38

Note: Models assessed the effects of covariate sets including anthropogenic features and landscape features on female pheasant survival in southwestern Beadle County, South Dakota. Models were compared with Akaike's information criterion adjusted for small sample sizes (AICc) and Akaike weights (wi). A total of 234 pheasants were monitored during 2017–2019 with 60 mortality events from raptor predation (*n* = 37), weather (*n* = 14), and mammalian predation (*n* = 9). Variables included in the final Cox PH model selection for raptor morality risk were landscape occupancy (**Land use[a]** = 1: perennial cover; 2: harvested; 3: other; **Land use[b]** = 1: tall vegetation; 2: emergent wetland; 3: other; **Land use[c]** = 1: emergent wetland; 2: other; **Land use[d]** = 1: perennial cover; 2: other; **Land use[e]** = 1: other; 2: harvested; **Land use[f]** = 1: emergent wetland; 2: tall vegetation; 3: woody; 4: harvested; 5: short vegetation; 6: other), distance to perches including woody features, powerlines, fencelines, and trees (**Perch**), distance to fencelines (**Fence**), distance to landscape edge (**Edge**), distance to roads (**Road**), distance to Conservation Reserve Program grasslands (**CRP**), distance to emergent wetlands (**Emergent wetlands**), distance to linear stands of low-growing trees and shrubs (**Woody**). Variables that were removed prior to model development included the density of woody features, roads, and emergent wetlands within four different radii of pheasant locations (i.e., 100, 200, 300, and 400 m radii) because of high correlation with proximity variables.

*All models included snow depth stratification.

Table 2-2. Tally of cause-specific mortalities for adult female pheasants during winter in southwestern Beadle County, South Dakota, 2017–2019 ($n_{2017} = 87$, $n_{2018} = 90$, $n_{2019} = 144$). All individuals were used in Kaplan-Meir survival probability estimates. Sixty individuals were censured from Andersen-Gill mortality risk models due to unknown cause of death, lacking relocation events, or unacceptable tracking error of ellipses.

	Survival				**Mortality Risk**			
Cause	**2017**	**2018**	**2019**	**Total**	**2017**	**2018**	**2019**	**Total**
Raptor	6	16	39	**61**	5	16	16	**37**
Mammalian	1	7	7	**15**	1	7	1	**9**
Weather	0	0	17	**17**	0	0	14	**14**
Unknown	4	1	12	**17**				
Censored	3	2	4	**9**	9	3	48	**60**
Detachment	1	0	0	**1**				
Total	**15**	**26**	**79**	**120**	**15**	**26**	**79**	**120**

Table 2-3. Winter weather statistics January-April in Beadle County, South Dakota during the study period (2017–2019) compared to 20-year averages (1999–2019).

	Maximum Temperature (°C)	**Minimum Temperature (°C)**	**Average Temperature (°C)**	**Snow Depth (cm)**	**Wind Speed (km/h)**
20-year average	4.0	-7.3	-1.5	7.0	17.8
2017	5.3	-5.4	0.1	2.3	17.5
2018	0.8	-9.7	-4.3	5.6	16.8
2019	-0.7	-10.0	-5.4	11.1	17.8

Table 2-4. Kaplan-Meier probability of survival models for adult female pheasant with staggered entry during winter in Beadle County, South Dakota, 2017–2019. Overall probability of survival was calculated from model averaged results across all 35 models.

Model	**AIC$_c$**	**ΔAIC$_c$**	**W$_i$**	**K**	**Deviance**
Snow + collar	796.93	0.00	0.29	4	788.92
Snow + weight + collar	798.25	1.32	0.15	5	788.23
Snow + group + collar	798.52	1.59	0.13	5	788.50
Snow + group + weight + collar	799.72	2.80	0.07	6	787.70
Snow	800.15	3.22	0.06	2	796.15
Snow + weight	800.93	4.00	0.04	3	794.92
Snow + group	801.03	4.10	0.04	3	795.02
Snow + group + weight	801.60	4.67	0.03	4	793.58
Snow + minimum temperature	801.67	4.74	0.03	3	795.66
Snow + year + weight	801.81	4.88	0.03	5	791.79
Snow + temperature variance	801.84	4.90	0.03	3	795.83
Snow + year	802.00	5.07	0.02	4	793.99
Snow + group + temperature variance	802.55	5.62	0.02	4	794.53
Snow + group + weight + temperature variance	803.07	6.14	0.01	5	793.05
Snow + year + weight + temperature variance	803.28	6.35	0.01	6	791.25
Snow + year + temperature variance	803.54	6.60	0.01	5	793.51
Snow + group + weight + temperature variance + minimum temperature	804.94	8.01	0.01	6	792.91
Snow + year + weight + temperature variance + minimum temperature	805.15	8.22	0.00	7	791.10
Snow + group + weight + temperature variance + minimum temperature + wind + collar	805.18	8.24	0.00	9	787.10
Snow + year + weight + temperature variance + wind	805.29	8.36	0.00	7	791.24
Snow + year + weight + minimum temperature + wind	805.75	8.81	0.00	7	791.70
Snow + weight + minimum temperature + temperature variance + wind	806.07	9.14	0.00	6	794.03
Snow + year + weight + temperature variance + minimum temperature + wind + collar	806.14	9.20	0.00	10	786.05
Snow + year + weight + temperature variance + minimum temperature + wind	807.15	10.22	0.00	8	791.10
Snow + year + temperature variance + minimum temperature + wind	807.25	10.31	0.00	7	793.20
Year + weight + temperature variance + minimum temperature + wind + collar	844.01	47.07	0.00	9	825.93
Year + temperature variance + minimum temperature	846.77	49.84	0.00	5	836.75

Continued.

Table 2-4. Continued

Model	**AIC_c**	**ΔAIC_c**	**W_i**	**K**	**Deviance**
Year + weight + temperature variance + minimum temperature	846.84	49.91	0.00	6	834.81
Year + weight + temperature variance	854.99	58.06	0.00	5	844.97
Year + weight	855.65	58.72	0.00	4	847.63
Year	856.74	59.81	0.00	3	850.73
Group	862.07	65.14	0.00	2	858.07
Group + weight	862.94	66.01	0.00	3	856.93
Temperature variance	901.61	104.68	0.00	2	897.61
Null	901.91	104.97	0.00	1	899.91

Note: Models assessed the effects of environmental parameters on female pheasant survival in southwestern Beadle County, South Dakota. Models were compared with Akaike's information criterion adjusted for small sample sizes (AICc) and Akaike weights (wi). A total of 221 pheasants were monitored during 2017–2019 with 120 mortality events. Environmental variables were averaged over weekly encounter histories and included average snow depth (**snow**), year the pheasant was monitored (**year**), GPS, DIY, or VHF collar type used (**collar**), weight of pheasant in kg at capture (**weight**), the average minimum temperature (**minimum temperature**), the variance between maximum and minimum temperature (**temperature variance**), average wind speed (**wind**). Additionally, we added a grouping variable to separate individuals during mild (2017-2018) winters from individuals during severe (2019) winters (**group**).

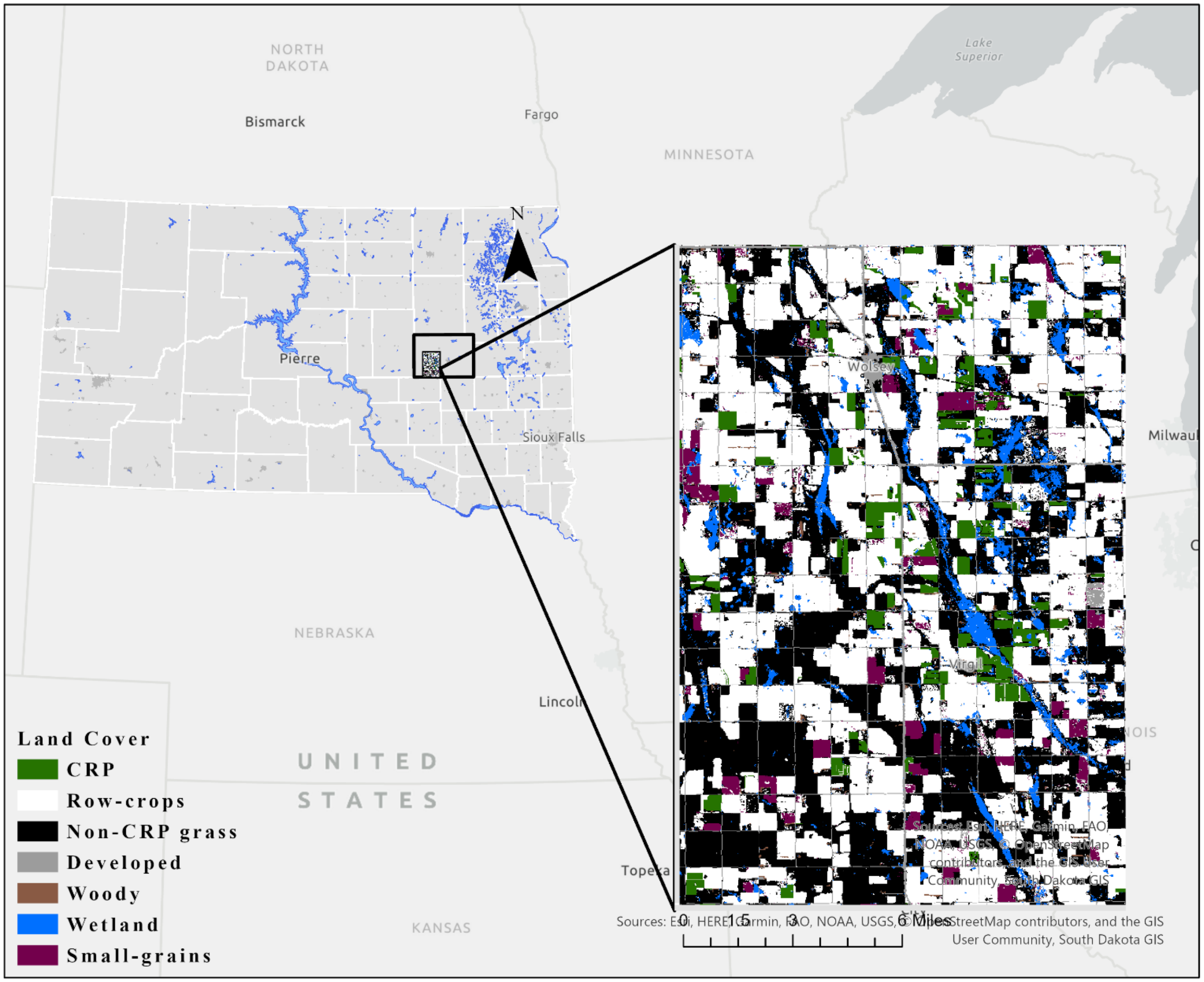


Figure 2-1. Study region for understanding ring-necked pheasant survival in southwestern Beadle County, South Dakota, 2017–2019

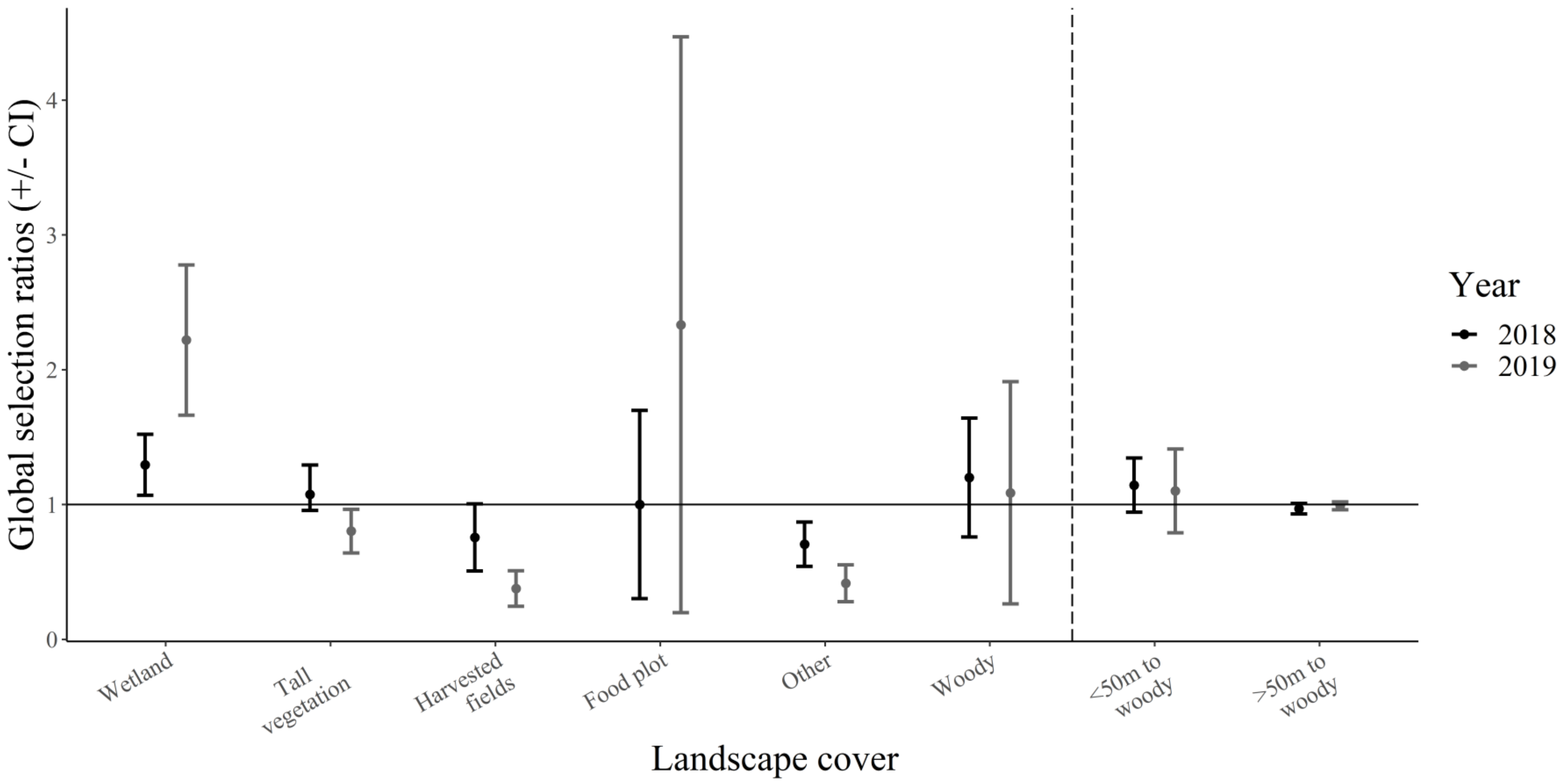


Figure 2-2. Resource selection ratios for adult female pheasants using Design III (Manly et al. 2002) sampling scheme. Values were taken from southwestern Beadle County, South Dakota during a mild (2018) and a severe (2019) winter. Individuals from 2017 are not represented in resource selection due to inadequate number of locations. A selection ratio and upper confidence interval <1 indicates landscape avoidance, a selection ratio and lower confidence interval >1 indicates landscape selection, and a selection ratio overlapping 1 indicates no landscape selection. The ‘other’ landscape category includes short vegetation, open water, and development. The 50 m distance to woody features was chosen to represent the environmental protection zone from a 5 ft woody features which are typical in the study region.

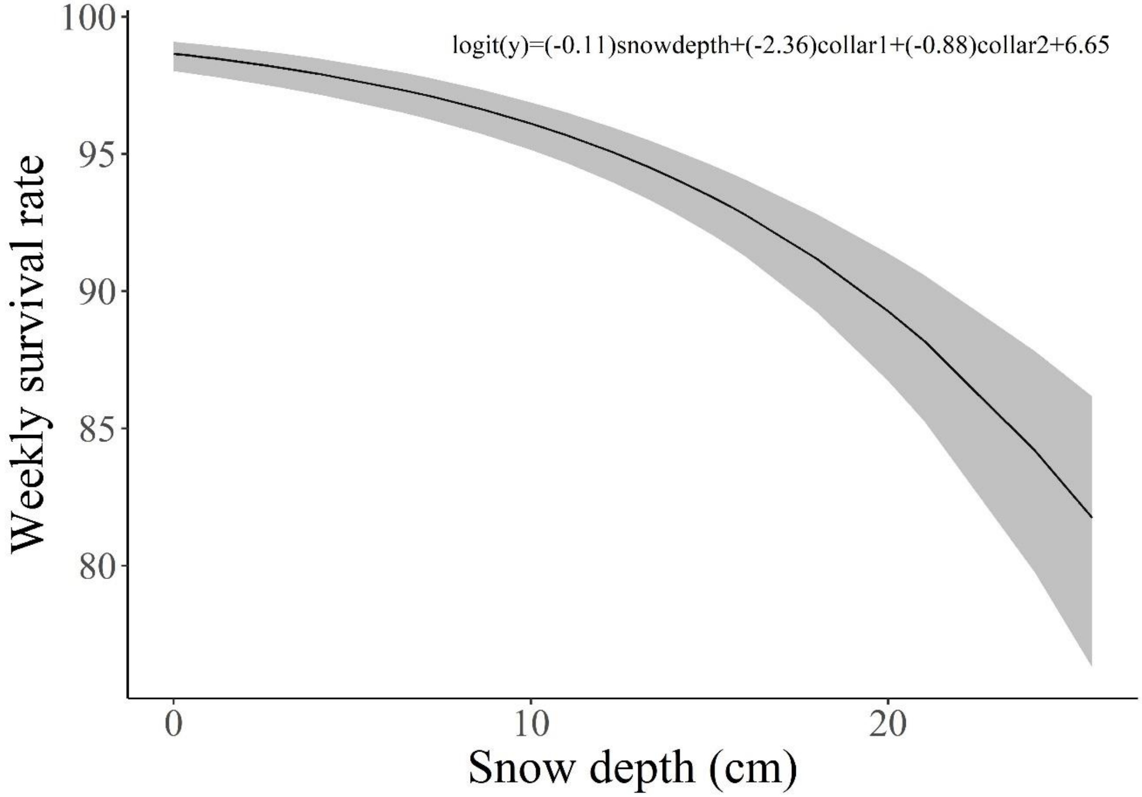
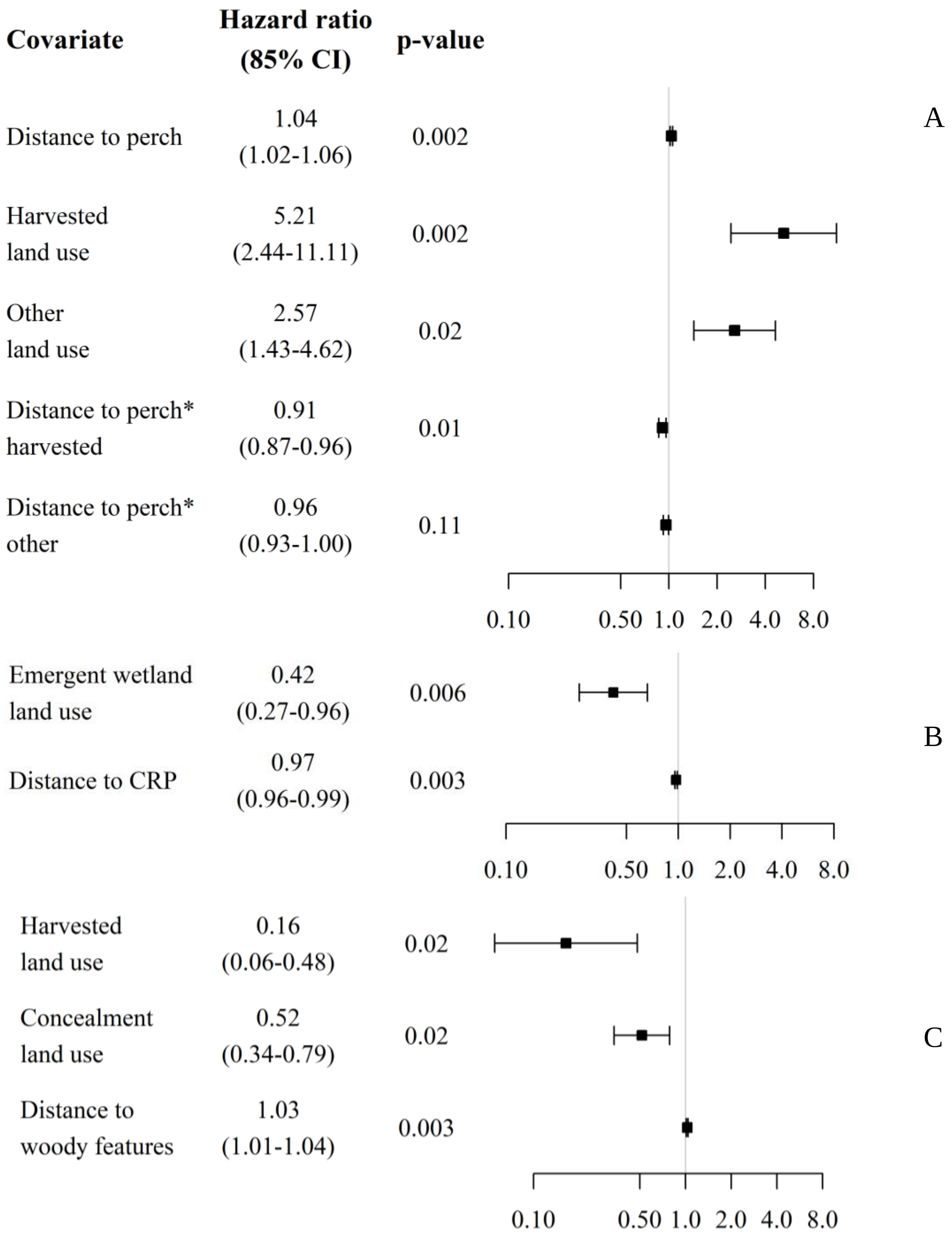


Figure 2-3. Model averaged coefficient estimates (β) and 95% confidence intervals for snow depth effects on weekly survival of adult female pheasants in southwestern Beadle County, South Dakota, 2017 – 2019 with transmitters.



Covariate	Hazard ratio (85% CI)	p-value
Distance to perch	1.04 (1.02-1.06)	0.002
Harvested land use	5.21 (2.44-11.11)	0.002
Other land use	2.57 (1.43-4.62)	0.02
Distance to perch* harvested	0.91 (0.87-0.96)	0.01
Distance to perch* other	0.96 (0.93-1.00)	0.11
Emergent wetland land use	0.42 (0.27-0.96)	0.006
Distance to CRP	0.97 (0.96-0.99)	0.003
Harvested land use	0.16 (0.06-0.48)	0.02
Concealment land use	0.52 (0.34-0.79)	0.02
Distance to woody features	1.03 (1.01-1.04)	0.003

Figure 2-4. Forest plots showing the hazard ratio of each covariate for A) raptor predation; B) weather-related mortality; and C) mammalian predation. A hazard ratio <1 indicates decreased risk of cause-specific mortality while a hazard ratio >1 indicates increased risk of cause-specific mortality. Values taken from southwestern Beadle County, South Dakota, 2017–2019.

CHAPTER 3: LOW-COST DIY GPS TRACKERS IMPROVE UPLAND GAME BIRD MONITORING

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ABSTRACT

We tested the possibility and feasibility of assembling Arduino GPS trackers without previous engineering experience and modified them for upland game birds under extreme environmental conditions. Low-cost GPS trackers were assembled and deployed on ring-necked pheasants (*Phasianus colchicus*) in conjunction with an ongoing winter survival study. To assess GPS receiver accuracy, we deployed trackers in a static test. The static test fix rate was 1.0, median error was 2.5 m and mean error of 13.3 m (SD = 39.5). During the mobile test, wild pheasants were captured using walk-in funnel traps baited with corn from January to March 2019. During winter, 407 VHF locations and 1574 GPS locations of 35 individuals were collected, resulting in a 287% increase in data density at only 23% increase in cost. The fix rate during the mobile test averaged to 0.83. To determine if trackers were low-cost, we calculated cumulative costs of equipment and supplies required to recreate the GPS tracking unit. GPS costs were $47.60 per unit with an additional $202.00 for the supplemental VHF transmitter.

Keywords: arduino, diy, gps, low-cost, modified trackers, Phasianus colchicus, ring-necked pheasant, telemetry

INTRODUCTION

Evaluating animal movements to gain ecological understanding of factors affecting behavior, survival, space use and resource selection has been a mainstay in wildlife management studies for decades (Craighead and Craighead 1965, Craighead et al. 1972, Gabbert et al. 1999). Animal movement data contribute to conservation and management of wildlife populations and should be collected with precision and accuracy. However, historical animal movement studies were often constrained by limited resources and rudimentary technology resulting in low-resolution movement data (Craighead and Craighead 1965, Van Ballenberghe and Peek 1971, Craighead et al. 1972). It is increasingly evident that low-resolution animal movement data have led to misrepresentation of home ranges and movements associated with use of important habitat patches, nocturnal activity or predatory activity (Horne et al. 2007a, Kochanny et al. 2009, Ruth et al. 2010). Technological advances in global positioning system (GPS) tracking devices for wildlife have made collecting high-resolution movement data possible. Unfortunately, the high cost of GPS tracking devices often prohibits large-volume or long-term application for low-budget projects.

Applications of high-resolution data requiring high spatial accuracy and fine temporal density include state-space and Brownian bridge movement models (Anderson-Sprecher and Ledolter 1991, Horne et al. 2007b). Such high-resolution spatial and temporal data is facilitated with GPS technologies (Guthrie et al. 2011). GPS technology in ecological research has fostered both environmental knowledge and research opportunity by increasing sampling frequency, density, size, accuracy, precision and analytic potential (Douglas-Hamilton 1998, Recio et al. 2010, Ruth et al. 2010, Guthrie et al. 2011). Commercial GPS receivers range from $535 to 1500 USD per unit for standard store-onboard technology with a lifespan of 1–2 years (Advanced Telemetry Systems, Lotek, Telonics). Currently, low-budget projects must choose between relatively low-resolution data collection with the use of many, less-costly, very high frequency (VHF) transmitters or high-resolution data collection with fewer, more expensive GPS receivers creating overall limitations on sample size (Cain and Cross 2018).

Although costs for commercial GPS units remain high, ‘do-it-yourself’ (DIY) projects providing free instructions for engineering designs have revolutionized technological advancements at reduced costs. Communities have collaborated to modify or develop wildlife tracking technology at fractional costs of commercially available trackers. By decreasing per unit expense, researchers can increase deployment rates, high-resolution data collection and analytic potential. For example, researchers have modified commercially available pet and vehicle tracking GPS devices for wildlife applications with costs ranging from $45 to 175 USD (Allan et al. 2013, Forin-Wiart et al. 2015, Fischer et al. 2018). Alternatively, development of Arduino-based GPS trackers as a light-weight wildlife tracking option range from $40 to 880 USD (Quaglietta et al. 2012, Cain and Cross 2018, McGranahan et al. 2018). Arduino is an opensource microcontroller that is widely used for DIY engineering projects (< www.arduino.cc >). Additionally, developing Arduino tracking devices allows for design flexibility and customization. However, there is hesitancy among practitioners to undertake a potentially engineering-intensive endeavor without engineering experience. As a result, the wildlife field has seen limited application of DIY or Arduino technology (McGranahan et al. 2018).

We tested the feasibility of assembling Arduino GPS trackers without previous engineering experience and modifying them for upland game birds under extreme environmental conditions. The objectives of this study were to: 1) implement low-cost Arduino GPS trackers into a ring-necked pheasant Phasianus colchicus (hereafter pheasant) study and 2) assess the practicality, accuracy and feasibility of building Arduino-based GPS trackers for wildlife research without previous engineering experience. We predicted that without previous engineering experience we could create trackers to collect high-resolution movement data with similar levels of accuracy as commercially available GPS receivers at a fractional cost. We assembled and deployed low-cost GPS trackers on pheasants in eastern South Dakota in conjunction with an ongoing winter survival study. We used Cain and Cross's (2018) open-source logger design with modified casing designs for upland game birds.

STUDY AREA

The study area covered a 270 km^2 area of Beadle County in eastern South Dakota. Beadle County experienced arctic air surges during the winter, resulting in average temperatures of −1.7°C (January–May 2019) with an average minimum and maximum temperatures of −17.8°C and 10.6°C (National Oceanic and Atmospheric Administration (NOAA); < www. noaa.gov/ >). Cumulative snowfall during the study was 548.62 cm (NOAA). The Beadle County landscape was 67% row-crop agriculture, pasture and hay (CropScape; < http:// nassgeodata.gmu.edu/CropScape/ >). The remaining 33% of the landscape was low range condition grassland, forest and wetland (CropScape).

MATERIAL AND METHODS

Tracker design: hardware and software

We assembled store-on-board GPS trackers using opensource schematics and instructions (< https://osf.io/jdrme/ >) (Fig. 3-1, Table 3-1, Cain and Cross 2018). After assembling the trackers, we had 12 g available for battery and casing options. This drove our decision to use a 9 g, 400 mAh battery lasting approximately 72 days while acquiring fixes every 7 h. Subsequently, the 400 mAh battery limited data accruement. However, researchers can increase the lifespan of trackers by substituting batteries with greater ampere hours within the recommended voltage (3.4–12 volts). With three grams remaining for casing, we chose heat-shrink tubing as a lightweight casing option. Initially, we experienced water-damage failures to 25% of trackers during the first trial due to leaks or punctures in the heat-shrink tubing. We then waterproofed the trackers with anti-corrosion lubricant (CorrosionX, Corrosion Technologies Corporation, Dallas, TX), a silicon packet, a second layer of heat-shrink tubing and sealed openings with bonding putty (Quik-cure epoxy, Bob Smith Industries, Atascadero, CA), which added negligible additional weight. Assembled trackers weighed 27–28 g.

We used open-source software to program the GPS trackers in the Arduino Integrated Development Environment (Cain and Cross 2018). Separate software was used to clear and read the memory (TNG_ReadClear.ino), and to program the microcontroller (TNG_logger.ino). The software is available for download from < https://bitbucket.org/ Splat01/gpslogger/src >.

Static test

We deployed trackers in a static test to assess GPS receiver accuracy in landscapes used by pheasants. Trackers were programmed to acquire satellite fixes for 60 s, record latitude, longitude, date and time at 30-min intervals over five consecutive days.

Six simultaneous static tests were run across a gradient of landscapes and canopy coverage to represent variable pheasant habitat. Tested landscapes included two sites with >75% canopy cover (shelterbelt), two sites with 10–50% canopy cover (cattail-wetland) and two sites with <10% canopy cover (grassland) (Guthrie et al. 2011). Canopy coverage was estimated using a spherical Model-C densiometer (Lemmon 1957) averaged over four cardinal directions at the tracker height. Trackers were affixed 25 cm to 1-m high poles at a 45° angle to simulate attachment to a gallinaceous bird (Guthrie et al. 2011). GPS tracker locations were compared against a commercially available handheld receiver (Garmin GPS 72, Olathe, KS). At each site we averaged locations for ≥100 position fixes from the handheld GPS receiver to achieve <3 m location accuracy (Oderwald and Boucher 2003). We calculated the fix rate by dividing the number of successful acquisitions over the number of attempted acquisitions (D'Eon and Delparte 2005). Locational errors were measured as the Euclidean distance between the tracker locations and the reference point (D'Eon and Delparte 2005). We measured the circular error probable (CEP) to provide the radius of circle that incorporates 50, 95, 99 and 100% of locations (D'Eon and Delparte 2005). We statistically compared differences in locational error among the three canopy coverage gradients using a post hoc Tukey test to determine if canopy obstruction impacts GPS accuracy (Cain and Cross 2018).

Mobile test

Backpack VHF transmitters (Model A1260, ATS) were attached to GPS trackers using J-B Weld plastic bonder (Fig. 3-1) (J-B Weld, Sulphur Springs, TX). The VHF transmitters were powered by a separate battery with an expected lifespan of 452–796 days. Backpack straps were created from Teflon ribbon (Telonics Inc., Mesa, AZ) with elastic inserts and were secured with crimped copper tubing and polyurethane adhesive (Gorilla Glue Company, Cincinnati, OH). Backpack straps were looped around wings, centered and securely tightened onto the pheasant (Fig. 3-2). With the additional VHF and harness material, completed tracking units weighed 42–43 g. GPS trackers were programmed to collect fixes every seven hours. We calculated fix rate by dividing the number of successful fixes over the number attempted (D’Eon and Delparte 2005).

We initially tested trackers during a pilot field deployment on farm-raised male pheasants (Gisi Pheasant Farms, Ipswich SD) that were GPS tagged, released, monitored four days per week, and retrieved upon detection of the mortality switch on the VHF transmitter.

After a pilot trial performance review, we water-proofed both refurbished and newly constructed trackers. We then captured wild male and female pheasants using cylindrical walk-in traps (12′ × 3′) with two funnel entrances (8″ × 8″) baited with corn Zea mays from January to March 2019. Pheasants were weighed to verify that trackers were within ≤5% of body mass (IACUC 16-086A) and were monitored four days per week. GPS trackers were retrieved upon detection of the activated mortality switch on the VHF transmitter.

Pheasants were located by radio-telemetry four times per week using a Windows compatible device (TM800W610L, NUVISION) with Locate III software (Pacer Computing, Tatamagouche, NS, Canada) in conjunction with a nullpeak truck-mounted telemetry system and a handheld GPS receiver to assign each bird with Universal Transverse Mercator (UTM) coordinates (UTM Zone 14N, NAD 1983 Continental United States). Radio-telemetry locations were estimated using ≥3 bearings with ≤1500 m2 error of ellipse. To determine observer accuracy, radio-telemetry locations taken from females during incubation, May-August, were compared against the nest location. Upon finding a nest, the location was obtained with a handheld GPS receiver averaged for ≥30 position fixes. We calculated observer accuracy as the average radial distance from radio-telemetry locations taken during incubation to the true nest location. The calculated observer accuracy was likely a conservative estimation due to stationary pheasants producing less tracking error than actively mobile pheasants.

Cost

To determine if trackers were low-cost, we calculated cumulative costs of equipment and supplies required to recreate the GPS tracker (Table 3-1). We compared costs to commercially available GPS trackers with similar functionality including store-on-board programming and battery-limited lifespans. Both DIY and commercial store-on-board trackers might have additional monitoring and retrieval costs such as salaries, gas and other infrastructure for VHF tracking. As these costs can vary widely among studies based on individual research objectives, we did not include costs of using VHF monitoring techniques. However, monitoring

or retrieval costs of store-on-board units would be identical between DIY and commercial units, thereby negating each other.

RESULTS

Static test

Collectively, the GPS trackers collected 1485 locations out of 1486 possible for an average fix rate of nearly 100% (Table 3-2). Locational errors differed between habitat types (F2,1484 = 89.6, $p < 2.2 \times 10{-}16$), but did not differ between cattail-wetlands and grasslands ($p = 0.05$). The smallest locational errors occurred in cattail-wetlands, followed by grasslands, and shelterbelts. The overall median error was 2.5 m and mean error of 13.3 m (SD = 39.5) (Table 3-2). Total CEPs ranged from 7.1 to 391.7 (Table 3-2).

Mobile tests

During the pilot trial from September to December 2018, we deployed 20 GPS trackers on farm-raised male pheasants. Trackers were deployed an average of 25 days and all were successfully recovered. Collectively, trackers accumulated 767 GPS locations with an average fix rate of 0.43. Data resolution was almost a two-fold increase over 276 VHF radio-telemetry locations acquired from the same 20 transmitters. Three trackers worked according to design during the entire deployment history. Five trackers experienced water damage and corrosion leading to premature failure. One tracker failed when the battery dislodged during deployment. One tracker prematurely failed because the GPS wiring became detached. The remaining ten trackers experienced inconsistencies in data collection presumably due to inadequate packaging.

After modifying and waterproofing our packaging, we deployed 35 trackers on wild pheasants (11 females; 24 males) from January to May 2019. On average, trackers were deployed for 26 days. Due to low winter survival, we re-deployed five GPS trackers on new individuals by recharging the batteries and repackaging the trackers. Eight trackers were not recovered because the pheasants either went missing or survived the duration of the study and were not recaptured. Overall, we simultaneously collected 510 VHF radio-telemetry locations and 1574 GPS locations of 35 individuals resulting in a 209% increase in data density at an average fix rate of 0.83.

Radio-telemetry accuracy was determined for three field personnel across two years using 57 known nesting females and 347 incubating locations. The average distance from the radio-telemetry location to the true VHF location was 89.27 m (±6.57).

Cost

Initial start-up costs for consumable supplies and assembly tools were $172.59 (Table 3-1). Thereafter, per unit costs were $47.60 with an additional $202.00 for the supplemental VHF transmitter (Table 3-1). Although the Arduino memory chip can ultimately record 16 000 locations, the 400 mAh rechargeable battery was expected to acquire ~248 locations leading to a cost of $1.00/location under perfect performance. During the pilot trial, associated costs were $2.34/ location, considering a 0.43 average fix rate. The costs per location during the second trial were approximately $1.21/ location with an improved average fix rate of 0.83. Additionally, we refurbished and redeployed trackers into the study after early mortality events by replacing the casing and harness and reusing the VHF at negligible costs resulting in ~$0.08/location. Otherwise, undamaged GPS trackers can be refurbished at the cost of a new VHF and casing, $223.46 (Table 3-1). Overall, we can create 50 GPS trackers at the cost of 8–24 commercially available receivers with similar store-on-board and battery powered functionality (Table 3-1) (Advanced Telemetry Systems, Telonics, Lotek).

DISCUSSION

The purpose of this study was to implement a low-cost wildlife tracker to improve high-resolution data collection. The development or modification of GPS trackers has numerous advantages for wildlife management including: 1) an increase in the number of studies with high-resolution locational data to understand wildlife spatial ecology and create better management guidelines; 2) the ability of researchers to design wildlife trackers with functionality customized to specific research designs and needs; and 3) competition of modified tracking devices with commercially available GPS devices which should drive down costs and increase technological innovation resulting in greater functionality in tracking devices at lower costs (Cagnacci et al. 2010).

Common inaccuracies associated with GPS telemetry are locational error and missing data that differ between GPS models, physical obstruction and canopy coverage (D’Eon and Delparte 2005, Cargnelutti et al. 2007, Hansen and Riggs 2008, Blackie 2010, Dennis et al. 2010). Due to these shortcomings, it is important to undergo rigorous testing and determine specific locational error and fix rates of trackers to understand potential location bias under specific study environments prior to deployment (D’Eon and Delparte 2005). Through static tests, we verified that our low-cost trackers had comparable precision and accuracy to commercially available trackers in landscapes used by pheasants. We found locational error and 95% CEP of our trackers was comparable to locational error and 95% CEP found in previous studies employing commercial trackers ranging from 9.6 to 15.5 m and 28.9 to 144 m respectively (D’Eon and Delparte 2005, Cargnelutti et al. 2007, Lewis et al. 2007, Dennis et al. 2010, Guthrie et al. 2011). Furthermore, our average GPS tracker locational error was a substantial improvement over VHF radio-telemetry and eliminated potential observer bias. Our findings also support previous studies, which demonstrated that canopy coverage influenced locational error (Frair et al. 2004, Lewis et al. 2007, Sager-Fradkin et al. 2007). Researchers should consider programming GPS trackers to record positional dilution of precision (PDOP) values as a method for screening locational outliers (D’Eon and Delparte 2005, Lewis et al. 2007). The 100% fix rate of our GPS trackers during static testing was similar to 67.6–100% fix rate of previous studies employing commercial receivers

(Frair et al. 2004, D’Eon and Delparte 2005, Lewis et al. 2007, Blackie 2010, Dennis et al. 2010).

Approximately 75% of our trackers functioned as intended during our second trial on wild pheasants with no instances of water-failure damage compared to only 20% during our first trial on farm-raised pheasants. Potential water damage is prevalent in most terrestrial environments and should be a consideration in casing designs (Gau et al. 2004, Blackie 2010). Our improved 83% fix rate during the second trial was within 41–95.8% fix rates found during mobile tests of previous studies employing commercial receivers (Gau et al. 2004, Cargnelutti et al. 2007, Blackie 2010, Dennis et al. 2010). The 17% failure-rates experienced during our second trial could be attributed to extreme temperatures, −34°C, that were below operational temperatures of our lithium-ion battery, −20 to 60°C. Additionally, there was one 0% fix rate from a tracker retrieved from the back of a badger den. Previous studies have found that sky obstruction can influence fix rates which may explain why this tracker failed while underground (Forin-Wiart et al. 2015). We included the 0% fix rate in the overall fix rate calculations because we cannot say with certainty whether the failure resulted from sky obstruction or manufacturing error. Therefore, our fix rate estimate is conservative to avoid overinflating device functionality.

Our per unit cost was similar to other modified low-cost trackers, $300–366.81 (Allan et al. 2013, Fischer et al. 2018). We found costs for the GPS component to be within $9 of the costs estimated by designers Cain and Cross (2018). Our cost per location ($1.21/location) was considerably lower than previously estimated costs of VHF ($10.55/location) and commercial GPS ($5.00/location) data collection (Guthrie et al.

2011, Thomas et al. 2011). Ultimately, reduced costs allowed us to deploy at least twice as many trackers than we would have deployed using commercial units.

High-resolution data provided insights into pheasant movement, behavior and survival estimates often misrepresented by VHF radio-telemetry. We supplemented 55 VHF transmitters with GPS trackers, increasing high-resolution data collection with 2341 additional locations at a 23% increase in cost per VHF transmitter. The intrinsic value of GPS locations became evident as researchers could not consistently monitor pheasant activity with heavy snowfall accumulation and extreme temperatures reaching −34°C during the study. Subsequently, increased data density revealed inter-daily movements and roosting locations that were not acquired by VHF radio-telemetry. Additionally, GPS data precision improved landscape-use and resource selection accuracy. For instance, GPS locations accurately captured pheasant utilization of narrow or patchy landscapes such as fence lines or ditches. Conversely, tracking errors of 89 m, associated with VHF telemetry may fail to overlap actual landscape use in patchy or narrow landscapes. Furthermore, survival estimates based on VHF mortality signal detection may be misrepresenting actual time of death. For example, we documented fixed locations from two GPS collars that indicated that time of death was 12 and 14 days prior to activation of the VHF mortality signal. Inaccurate time of death may create bias when modeling time-dependent survival estimates. Ultimately, by using low-cost DIY GPS trackers, we increased GPS deployment thereby increasing data density and location precision.

Aside from the numerous benefits of DIY GPS trackers, caveats included limited lifespan, device weight and store-onboard technology. The trackers were built at the maximum weight capacity for pheasants to maximize data accruement. However, concerns regarding the influence of GPS receiver weight on survival and behavior may limit application for smaller species (Foster et al. 2018, Severson et al. 2019). Therefore, researchers should be weary of weight thresholds for specific species. Additionally, life expectancies >1.5 years would require larger batteries to monitor individuals throughout life histories. Consequently, larger batteries increase overall device weight. Widely used GPS technology includes store-on-board memory and remotely downloadable memory. Store-on-board technology requires device retrieval resulting in additional time, personnel, cost and effort allocated to monitoring and recovering devices. Remote download technology is currently more expensive for the hardware but eliminates these obstacles. Using DIY GPS trackers comes with possible limitations, including failures associated with manufacturing error. We recommend practitioners test their trackers prior to large-scale deployment under conditions consistent to their study to ensure functionality. Practitioners should modify or remove any trackers exhibiting failure prior to large-scale application to prevent compromising the objectives of their study. DIY technology can continue to foster and reinvent tracking technology to facilitate more research needs including remote download capabilities, higher lifespan and lighter weight at reduced costs. Innovations will continue to facilitate high-resolution data collection in wildlife research.

Arduino is a growing platform that fosters creativity and open-source integration. Many current designs could be improved or implemented into the wildlife field. There are multiple monitoring projects currently used to alert of food levels (e.g. ‘Squirrel Feeder Tweet’) or dispense food (e.g. ‘Arduino Uno-based’, ‘Easy to Build Pet Feeder’). Dispensing or alerting applications are extremely useful, for example, micro-controlled long-term scent dispensers were used to remotely monitor wolverine populations in Idaho (Whitham 2015). Physiological monitoring Arduino projects including ungulate delivery alerts (e.g. ‘Foaling Monitor’) and egg-laying sensors (e.g. ‘Automated Safe Chicken House’) could be useful for neonate or nesting studies. Additional wildlife monitoring efforts with Arduino include camera traps (e.g. ‘Arduino Wildlife Night Camera’) and weight-activated webcams on bird feeders for abundance estimates (e.g. ‘It’s for the birds’). Arduino is also commonly applied to motor-based projects applicable to trapping efforts that open and close doors using daylight sensors (e.g. ‘Automated Safe Chicken House’) or regulate doors (e.g. ‘The Arduino Gatekeeper’). Furthermore, potential applications for depredation hazing include deterring unwanted visitors on vegetation by shaking limbs (e.g. ‘Limb Shaker’) or motion-sensor sound alarms that capture photographs (e.g. ‘DogWatcher’). Regardless of need or study, the capabilities of open-source platforms provide researchers a new and exciting tool for studying wildlife.

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Table 3-1. Equipment required for building GPS trackers.

		Part	Price	Source
Start-up	**Manufacturing**	Solder paste	15.95	amazon.com
		Flux paste	4.49	amazon.com
		Soldering kit	25.99	amazon.com
		Wire strippers	5.00	amazon.com
		Wire cutters	4.43	amazon.com
		Laser thermometer	12.59	amazon.com
		Frying pan	4.49	amazon.com
	Programming	FTDI adapter	14.95	sparkfun.com
		USB	1.95	sparkfun.com
	Packaging	Heat gun	28.06	amazon.com
		Quik-Cure Epoxy	15.87	amazon.com
		CorrosionX	8.81	amazon.com
		Heat shrink tubing	5.64	amazon.com
	Harness	1/8" Elastic	3.52	amazon.com
		Outdoor thread	4.56	amazon.com
		Copper tubing	4.44	amazon.com
		Gorilla glue	5.97	amazon.com
		JB weld-plastic weld	5.88	amazon.com
		Total	**172.59**	
Single-Use	**GPS Components**	SMD transistors	0.07	lcsc.com
		Connector pins	0.07	lcsc.com
		Printed circuit board	0.30	easyeda.com
		Male battery connector	0.93	digikey.com
		Female battery connector	1.03	digikey.com
		Memory integrated circuit	0.85	digikey.com
		GPS receiver	15.95	sparkfun.com
		Arduino Pro Mini	9.95	sparkfun.com
		Battery	4.95	sparkfun.com
	Harness	Teflon Ribbon 0.25"	13.50	Telonics, Inc.
		VHF transmitter	202.00	Advanced Telemetry Systems
		Total	**249.60**	
Refurbished Cost	**Harness**	Teflon Ribbon 0.25"	13.50	Telonics, Inc.
		VHF transmitter	202.00	Advanced Telemetry Systems
		1/8" Elastic	3.52	amazon.com
		Copper tubing	4.44	amazon.com
		Total	**223.46**	
Example Cost for 50 units			**12,733.48**	

Table 3-2. Locational errors and fix rates of self-made wildlife trackers during static tests at test sites in Beadle County, South Dakota 2018.

Canopy Coverage (%)	N	Fix rate	Locational error (m) Mean (SD)	Median	50%*	95%*	99%*	100%*
0-10	492	1.0	8.4 (26.3)	2.2	2.1	45.9	158.0	252.8
10-50	504	1.0	2.8 (3.8)	2.2	2.4	5.1	8.1	71.3
75-100	491	~1.0	29.1 (60.6)	4.5	4.6	158.5	304.0	391.7
Total	1487	1.0	13.3 (39.5)	2.5	7.1	80.4	209.0	391.7

*Radius of circle that incorporates 50%, 95%, 99%, 100% percentage of locations

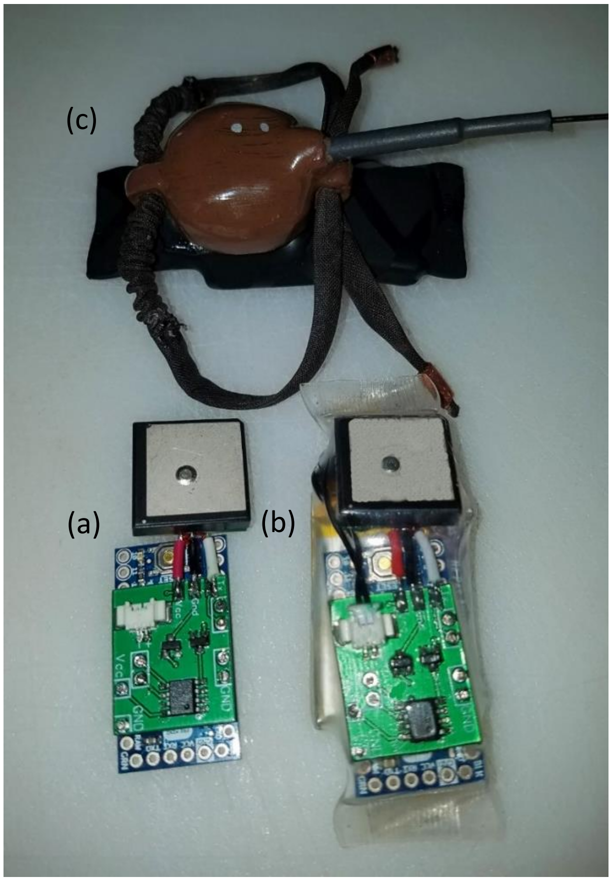

Figure 3-1. Stages of self-made GPS tracker a. assembled GPS tracker; b. water-proofed tracker, silicon packet, and battery in one layer of heat-shrink tubing; c. VHF transmitter attached to tracker in second layer of heat-shrink tubing.

Figure 3-2. Self-made, low-cost GPS tracker weighing 43 g (<5% of body mass) attached to a male ring-necked pheasant in Beadle County, South Dakota, 2019.

APPENDIX 2.1

Table A1. AIC_c model selection results for landscape classification variables to be used in proportional hazard rate models of pheasant mortality risk during winter in Beadle County, South Dakota, 2017-2019.

Land-cover classification	**k**	**AIC_c**	**ΔAIC_c**	**w_t**	**LL**
Raptor risk (*n* = 37)					
Perennial cover* + Other	1	1207.33	0.00	0.55	-602.67
Perennial cover* + Harvested fields + Other	2	1209.33	2.00	0.20	-602.66
Harvested fields + Other	1	1210.94	3.61	0.09	-604.47
Emergent wetlands + Tall grassland + Other	2	1210.98	3.64	0.09	-603.48
Emergent wetlands + Other	1	1211.86	4.53	0.06	-604.93
Emergent wetlands + Tall grassland + Woody + Harvested Fields + Short herbaceous vegetation + Other	5	1214.20	6.87	0.02	-602.09
Weather risk (*n* = 14)					
Emergent wetlands + Other	1	321.11	0.00	0.62	-159.55
Emergent wetlands + Tall grassland + Other	2	322.91	1.80	0.25	-159.44
Emergent wetlands + Tall grassland + Woody + Harvested Fields + Short herbaceous vegetation + Other	5	324.89	3.78	0.09	-157.38
Perennial cover* + Harvested fields + Other	2	328.18	7.06	0.02	-162.08
Perennial cover* + Other	1	328.41	7.30	0.02	-163.20
Harvested fields + Other	1	330.20	9.08	0.01	-164.09
Mammalian risk (*n* = 9)					
Perennial cover* + Harvested fields + Other	2	489.61	0.00	0.74	-242.80
Harvested fields + Other	1	492.21	2.60	0.20	-245.10
Perennial cover* + Other	1	496.10	6.49	0.03	-247.05
Emergent wetlands + Other	1	496.80	7.19	0.02	-247.40
Emergent wetlands + Tall grassland + Other	2	498.69	9.08	0.01	-247.34
Emergent wetlands + Tall grassland + Woody + Harvested Fields + Short herbaceous vegetation + Other	5	500.36	10.75	0.00	-245.16

*Perennial cover includes emergent wetlands, tall grassland, woody, and food plot