

AN ASSESSMENT OF THE USEFULNESS OF WINTER
WHEAT FOR NESTING DABBING DUCKS IN
NORTH AND SOUTH DAKOTA

by

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ABSTRACT

The Prairie Pothole Region (PPR) of North America is highly valuable for breeding waterfowl, however over the last century has been predominantly converted to some form of agriculture. With the recent increase in economic value of some cash-crops and the potential to lose highly valuable nesting habitat in the Conservation Reserve Program (CRP), there has been interest in evaluating alternative farming practices to provide additional breeding habitat for waterfowl. We evaluated and compared daily survival rates (DSR) of nests in winter wheat to nests in perennial cover and examined the number of hatched nests per hectare in each habitat to put habitat-specific estimates of nest survival in perspective. We studied nest survival of duck nests (*Anas* spp.) in winter wheat (n=1,170) and perennial cover (n=3,041) in the PPR of North and South Dakota on 13 to 19, 10.36-km² sites each year between 2010 and 2012. . We used an information-theoretic approach to develop and evaluate a set of competing models based on covariates of interest and what has been established important in the waterfowl nest-survival literature. Our top model included a set of covariates that were either highly or moderately supported in all of the models that received substantial amounts of support from the data. Across all species, we found evidence that nest survival was at least as high in winter wheat as in perennial cover, and for several species, estimated nest-survival rates were higher in winter wheat. Nest survival also varied by year and study area, was positively related to nest age and vegetation density, and was negatively related to the number of wetland basins and the proportion of cropland in the landscape. Our estimates for hatched nests per hectare were twice as high in perennial cover compared to values for winter wheat fields. However, estimates for fields of winter wheat were 6.5 times higher than estimates in spring wheat fields. Our results provided evidence that winter wheat could be a useful tool for wildlife managers seeking to add nesting habitat in landscapes used for modern agriculture.

INTRODUCTION

The Prairie Pothole Region (PPR), which extends from the south-central portion of Canada including Alberta, Saskatchewan, and Manitoba, down to the north-central portion of the United States including Montana, North Dakota, South Dakota, Minnesota, and Iowa, produces more than 50% of all ducks in North America (Smith et al. 1964). This unique area is characterized by thousands of small, depressional wetlands (potholes) throughout the landscape as a result of glaciations over 10,000 years ago (van der Valk 1989). Although the PPR has tremendous value as a natural resource, it is also very valuable for agricultural production. Over the last century there has been a major shift in land use from native mixed and tall grass prairie to agriculture in the form of cultivated crops, pastures, and rangeland (Dahl 1990).

Hoekman et al. (2002) showed that nest success was one of the most important factors for population growth of mallards (*Anas platyrhynchos*) and presumably other upland nesting duck species (Pieron and Rowher 2010). With the drastic change in land use, wildlife managers are always looking for ways to increase available nesting cover. Programs like the Conservation Reserve Program (CRP) were initiated over 30 years ago to re-establish grassland habitat, protect air and water quality, and reduce soil erosion caused by the intensification of agriculture (Reynolds et al. 2001). CRP offers landowners a monetary incentive to voluntarily take their fields out of production and establish perennial grass or tree cover for 10-15 years. This program has been positively associated with nest success and recruitment rates of breeding ducks (Reynolds et al. 2001, Drever et al. 2007); however acreage enrolled in the program has significantly

declined over the last five years and this negative trend is predicted to continue (U.S. Department of Agriculture Farm Service Agency 2013). With the growing prices for some cash crops and the push to produce biofuels, the economic incentive is greater to convert what is left of the native prairie or CRP to cropland (Claassen et al. 2011).

Although previous studies have documented waterfowl nesting in cropland (Higgins 1977, Cowan 1982, Lokemoen and Beiser 1997), our knowledge of the importance of croplands to nesting ducks remains limited due to the difficulty of obtaining adequate sample sizes while avoiding crop destruction (Devries et al. 2008). The few studies that have been able to quantify nest success and apparent nest density have reported extremely low estimates for both (Cowardin et al. 1985, Klett et al. 1988, Greenwood et al. 1995). Although predation is the predominant cause of nest failure for upland nesting ducks (Higgins 1977, Duebbert and Kantrud 1987, Sovada et al. 2001, Pieron and Rowher 2010), nests initiated in spring-seeded cropland also face risks of destruction from farming processes including seeding, tillage, and spraying operations during a critical period of the nesting season (Devries et al. 2008).

Conversely, fall-seeded crops are planted in the fall, remain dormant through the winter, and begin growing in the spring before ducks arrive to nest, providing a layer of cover for early-season nesting birds. Furthermore, nests in fall-seeded crops are not exposed to seeding and tillage operations during the spring. Devries et al. (2008) reported higher nest success and apparent nest density in winter wheat and fall rye when compared with spring-seeded crops in the parklands and grasslands of Saskatchewan. Other studies in Canada (Cowan 1982) and in the United States (Duebbert and Kantrud

1987) have shown similar results with no-till cropland. We were interested in exploring winter wheat, a fall-seeded crop, as a suitable nesting habitat for breeding ducks in the PPR of the United States.

Our objectives were to determine if ducks nest in winter wheat and assess species-specific use by the five most common upland nesting species: Blue-winged teal [*Anas discors*], Gadwall [*A. strepera*], Mallard, Northern Pintail [*A. acuta*], and Northern Shoveler [*A. clypeata*]. We also wanted to evaluate and compare daily survival rates (DSR) of nests in winter wheat to DSRs of nests in perennial cover. Based on previous research (Duebbert and Kantrud 1987, Devries et al 2008), we hypothesized that DSR would be similar for nests in winter wheat and perennial cover. As a secondary objective, we also wanted to assess the number of hatched nests per hectare in each habitat and compare them with numbers in spring wheat. We did not evaluate nest abundance because the number of nests initiated and failed between searches is unknown (Devries et al. 2008) and because some nests go undetected with the search methods we used (Higgins et al. 1977, Gloutney et al. 1993). However, given that (1) we consistently searched each field every 3 to 4 weeks, (2) it takes approximately 35 days for a nest to go from initiation to hatching, and (3) a recent report indicated that repeated nest searching misses few successful nests (G. Péron, personal communication) we believe that we found most of the nests that were initiated and hatched during our study. Thus, we provide information on the number of hatched nests per hectare in each habitat to put habitat-specific estimates of DSR in perspective. We expected the number of hatched nests per hectare to be lower in winter wheat compared to perennial cover due to the

characteristics associated with monoculture habitats; however, given the previous research with spring-seeded crops, we expected the number of hatched nests per hectare to be much lower overall in spring wheat.

STUDY AREA

We conducted our study from 2010 to 2012 in the Missouri Coteau and Drift Prairie regions of North and South Dakota (Figure 1). In all three years we had a study area near Minot, North Dakota ($48^{\circ} 13' 59''$ N, $101^{\circ} 17' 32''$ W) in the northwest region (NWR) of the state. In 2011, we also included a study area in the south-central region (SCR) near Ashley, North Dakota ($46^{\circ} 2' 6''$ N, $99^{\circ} 22' 25''$ W). This study area was included to increase our scope of inference about winter wheat in landscapes of varying amounts of grassland and cropland, but we were unable to retain it for the duration of the study due to the difficulty of finding winter wheat producers to work with in the area.

Both regions were dominated by small grain, oil seed, pulse crops and row-crop agriculture. The SCR also contained a large portion of grazed pasture land. Areas of natural upland habitat were highly fragmented remains of mixed prairie with most of the perennial cover in the form of hay, pasture (grazed and ungrazed), idle cover enrolled in the CRP, or patches alongside roadways (right-of-ways).

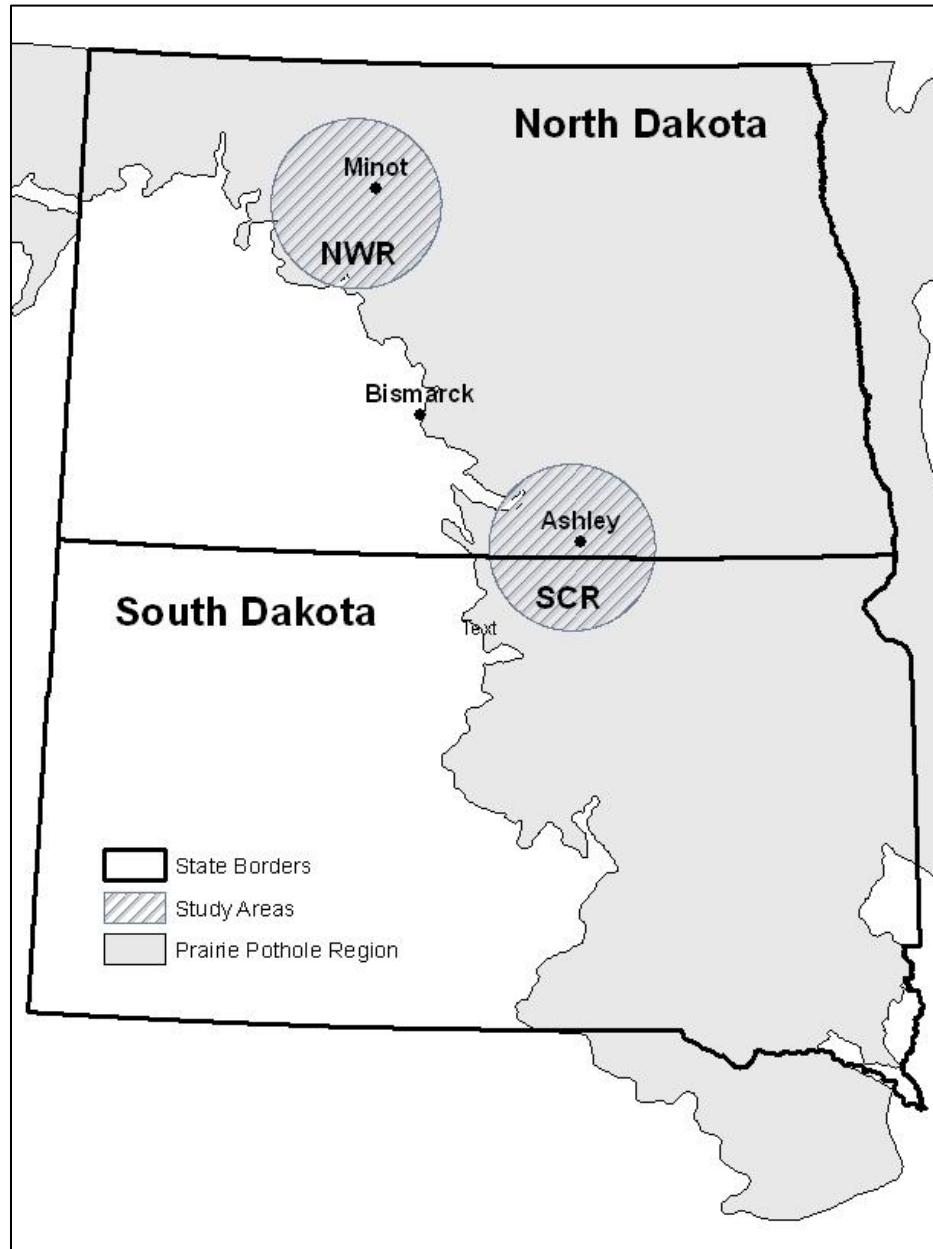


Figure 1. Location and extent of the study areas (NWR = North west Region, SCR = South-central Region) used to examine nest success in the Prairie Pothole Region of North and South Dakota, during the summer 2010-2012. The SCR was only used during the summer of 2011.

METHODS

Study Design

We conducted our research on 13 sites in both 2010 and 2011, and 19 sites in 2012. Each site was a 10.36 km² (4 mi²) area that contained at least one winter wheat field and one perennial cover field. We included grassland, CRP, pasture, hayfields, and right-of-way as perennial cover. Initially we attempted to randomly sample for winter wheat fields in our study areas, but abandoned this method because of the unpredictability of where winter wheat would be planted each year. Instead, we canvassed producers in the study area who were known to have purchased winter wheat seed and sought permission to search for nests in their winter wheat fields.

Where permission was granted, we narrowed our selection to fields that contained at least 50 wetland basins within 10.36 km² of the center of the field. We chose our scale based on previous work done by Stephens et al. (2005) and Walker et al. (2013) that showed accounting for basin count at the 10.36 km² scale to be important when assessing nest survival of upland nesting ducks. Basins included wetlands that were wet or dry to account for permanent, semi-permanent, temporary, and seasonal wetlands. Based on the HAPET thunderstorm map developed by USFWS, areas with at least 50 wetland basins are predicted to support at least 20 breeding duck pairs, a level that would allow us to efficiently find nests. We then stratified our sites into categories of high, medium, and low determined by the range of basins at the 10.36 km² scale within our study areas. We

sampled our sites evenly from these categories and considered convenience of location if we had more than enough fields to choose from in each category.

Once we had a winter wheat field that met our criteria, we located ≥ 1 perennial cover field within 10.36 km² of the winter wheat field for which we could gain permission to conduct nest studies. For a few winter wheat sites, we either could not obtain permission or could not find areas of perennial cover within 10.36 km². In those few cases, we used another field of perennial cover further away that had the appropriate number of wetland basins in the surrounding landscape to match that of the winter wheat field of interest.

Field Methods

We systematically nest searched our sites 2-3 times from late April to mid-July at approximately 3-4 week intervals using the drag method described by Klett et al. (1986). We dragged a nylon rope between two all-terrain vehicles to flush nesting hens, get a visual mark on where the hen flushed, and locate the nests. A nylon rope was used rather than a chain to minimize damage to the wheat. Searches were conducted between 0700 and 1400 hours (Gloutney et al. 1993). Once a nest was found, we determined and recorded the species, number of eggs, nest age, date, vegetation density, location in geographic coordinates, and status of the nest.

We determined the species based on visual features of the female that flushed from the nest or by examining feathers found in the nest bowl (Klett et al. 1986). We determined the age of each nest by candling several eggs from the nest to estimate

incubation stage of the eggs and then using that age and the clutch size in the nest to calculate initiation date (Weller 1956). A robel pole was used to record visual obstruction readings (VORs) to the nearest 5 cm in four cardinal directions, 4 meters from the nest at a height of 1 meter (Robel et al. 1970) and nest-site vegetation density was estimated by averaging the 4 measurements. The geographic coordinates were recorded using a handheld Global Positioning Systems unit and the nest was marked with a 1-meter high fiberglass pole and pink flagging, 4 meters north of the nest to make relocation easier.

We continued to monitor nests every 7-10 days until they were hatched, destroyed or abandoned. We determined a successful nest to be one that hatched at least one egg. Nests destroyed or abandoned were considered failed nests and any nest considered abandoned due to investigator influence was excluded from the analysis.

Covariates of Interest and Hypotheses

We developed a list of covariates for use in competing models of daily nest survival based on our research questions and what has been established important by the waterfowl nest-survival literature. Habitat was included in the list to allow us to evaluate a possible difference in survival rates for nests in winter wheat (WW) versus perennial cover (PC). We included species (Blue-winged Teal [BWTE], Gadwall [GADW], Mallard [MALL], Northern Pintail [NOPI], and Northern Shoveler [NSHO]) to account for expected variation, with blue-winged teal, gadwall and northern shovelers predicted to have higher nest survival estimates than mallards and northern pintails (Klett et al.

1988, Beauchamp et al. 1996, Pieron and Rowher 2010). Study area (NWR and SCR) and year (2010, 2011 and 2012) were included as categorical predictor variables that might explain potential temporal and spatial variation in nest survival (Dinsmore et al. 2002).

Nest age, calendar date, wetland basins, proportion of cropland, and vegetation density were included as continuous variables. We expected nest survival to increase with nest age (Stephens et al. 2005, Grant and Shaffer 2012, Walker et al. 2013) because of modified hen activity at the nest as the season progressed (Forbes et al. 1994), or because nests at higher risk will fail at a younger age (Klett and Johnson 1982). We included calendar date to account for possible seasonal variation in nest survival rates. Calendar dates were standardized among years by using the earliest date a nest was found for any year as the first day of the season and the last date a nest was successful or failed.

The number of wetland basins and proportion of cropland (including winter wheat) in the landscape were both calculated using ArcGIS 10.1 and satellite imagery layers from the National Wetlands Inventory (NWI) and the United States Department of Agriculture National Agricultural Statistics Service (USDA NASS), respectively. Stephens et al. (2005) pointed out the importance of accounting for the number of wetland basins in the landscape when assessing nest survival, and consistent with their study we predicted a negative relationship between nest survival and the number of wetland basins at a 10.4 km² scale. We also expected the proportion of cropland at the 41.4 km² scale (Stephens et al. 2005) to be negatively related to nest survival (Greenwood et al. 1995, Reynolds et al. 2001, Drever et al. 2007, Bloom et al. 2013).

The conversion of grassland to cropland often results in fragmented patches in the landscape (Gehring and Swihart 2003) and a decrease in patch size (Saunders et al. 1991). Foraging patterns are likely affected by fragmentation, and it is believed that foraging efficiency of predators is higher in smaller patches of habitat such that nest survival in smaller patches is lower (Greenwood et al. 1995, Sovada et al. 2000, Phillips et al. 2003, Stephens et al. 2005).

Vegetation density at the nest was expected to have a positive relationship with nest survival (Warren et al. 2008, Thompson et al. 2012, Bloom et al. 2013). We hypothesized that thicker amounts of vegetation would decrease foraging efficiency of predators, conceal nests better, and have a positive effect on nest survival (Sugden and Beyersbergen 1987, Stephens et al. 2005).

Modeling of Daily Nest-Survival Probability

We used an information-theoretic approach (Burnham and Anderson 2002) and developed a set of models based on our covariates of interest. Using the all-combination strategy recommended by Doherty et al. (2010), we ran all-possible linear additive combinations with our covariates, but held species constant within all models as a baseline covariate to account for expected variation (Stephens et al. 2005, Walker et al. 2013). An intercept-only model was included for comparison. To explore possible interactions and potential nonlinearities that have been reported by previous work, we included interaction terms between species and habitat (Klett and Johnson 1982, Stephens et al. 2005, Walker et al. 2013), species and nest age (Grant and Shaffer 2012), and a

quadratic term for nest age (Grant et al. 2005, Pieron and Rowher 2010, Grant and Shaffer 2012). We also checked for, but did not find, evidence of strong collinearity between covariates before proceeding to model the data.

We used program MARK (White and Burnham 1999) through the RMARK package (Laake 2013) in program R (R Development Core Team 2013) to model daily survival rate as a function of nest and landscape-scale covariates. This method uses a maximum likelihood approach and assumes that (1) nests are accurately aged when found; (2) nest fates are assigned correctly; (3) finding and monitoring a nest does not influence its fate; (4) nest fates are independent of one another; and (5) no heterogeneity exists among daily survival rates of nests as modeled (Dinsmore et al. 2002). For assumption one, we candled the eggs to determine the incubation stage (Weller 1956) when the nest was found and subsequently with each return visit to confirm incubation was progressing and the nest was accurately aged. For the second assumption, evidence to discriminate between hatched and failed nests was discrete (Klett et al. 1986), and any nests fated unknown were excluded from the analysis. For the third assumption, we minimized the amount of time (<5 minutes) and disturbance at the nest when found and on later visits. For the fourth assumption we tested for overdispersion (\hat{c}) by bootstrapping our data at the field-level (Bishop et al. 2008). We ran over 1,000 simulations directly in Program MARK using a highly parameterized model. Estimates and standard error of daily survival were calculated based on estimated coefficients for each simulated data set for nests aged 5 to 35 days (ages of nests that were common in our data). All other covariates were held at their mean values. We calculated the

standard deviation of the estimates for each nest age. We then calculated the average standard error for daily survival rates for each nest age and used the following equation to estimate overdispersion for each age:

$$\hat{c} = \frac{\text{Standard Deviation}^2}{\text{Standard Error}^2}$$

Our final estimate of overdispersion was obtained by averaging the age-specific overdispersion estimates, which were very consistent.

For the fifth assumption, we assumed that we adequately modeled heterogeneity that exists in our data. To our knowledge, there is no goodness-of-fit test available that is unbiased and practical given the size of our dataset (Sturdivant et al. 2007, Walker et al. 2013). Also, Burnham and Anderson (2004) showed through a simulation example, that often the most general model does fit the data.

We used a logit link with a binomial error distribution to model daily survival rate with:

$$DSR_{ji} = \frac{\exp^{\beta_{0+} + \sum_j \beta_j x_{ji}}}{1 + \exp^{\beta_{0+} + \sum_j \beta_j x_{ji}}}$$

Here, DSR_{ji} is the daily survival rate for the j th covariate on the i th day. β_0 is the intercept, β_j is the estimated coefficient for the j covariate, and x_{ji} is the value for the j covariate on day i (Rotella et al. 2004).

Akaike's Information Criterion with a correction for small sample size and our estimate of overdispersion (QAICc; Burnham and Anderson 2002) was used to rank our models and assess which were most important for evaluating DSR. We used the QAICc value associated with each model to rank them and assessed importance by considering

the ΔQAICc value and QAICc weight (ω_i) associated with each model. The ΔQAICc value was calculated by subtracting the QAICc value of the model with the lowest score from the respective model's QAICc value being assessed. Models that were ≤ 2 ΔQAICc units were considered strongly supported by the data and models ≤ 7 ΔQAICc units were considered moderately supported by the data (Burnham and Anderson 2002). We also determined if any models that were well-supported contained uninformative parameters (Arnold 2010) and took this into consideration when making inferences about our covariates. We used a 35-day incubation period (average number of days needed for most *Anas* spp. nests to hatch) when converting estimates of DSR to point estimates of nest success (Klett et al. 1986). Nest success estimates for each categorical variable (species, habitat, year, and study area) were calculated from our top model while holding all continuous variables (basin count, nest age, cropland, and VOR) at their mean values, unless otherwise stated. The delta method was used to calculate standard errors (Powell 2007).

Hatched Nests per Hectare

We calculated the number of hatched nests per hectare in each habitat and year. We tracked the amount of hectares searched with a Garmin eTrex GPS unit. The data was downloaded using the Department of Natural Resource's Garmin software (DNRGarmin.exe version 5.04) and uploaded in ArcGIS where geometry tools were used to calculate the amount of hectares searched. For each habitat, we determined the

number of nests successful (≥ 1 egg hatched) and divided by the number of hectares searched.

In 2010, we also collected data in spring wheat fields which we include in this section to provide perspective on how hatched nests per hectare in winter wheat compare to a spring-seeded crop. We collected data in spring wheat only in 2010 due to financial limitations and the limited sample size collected in this habitat, which was consistent with reports from other studies in spring-seeded crops (Higgins 1977, Greenwood et al. 1995, Devries et al. 2008).

RESULTS

Summary of Findings

We found and monitored 1,170 nests in winter wheat and 3,041 nests in perennial cover for the five most common upland nesting ducks. This resulted in an effective sample size of 50,422 observations for estimating daily survival rates. The number of nests varied among habitats, species, and years (Table 1). The most common nesting species in winter wheat were northern pintails and mallards (24% each), followed by gadwalls (22%), blue-winged teals (18%), and northern shovelers (12%). In perennial cover, the most common nesting species were blue-winged teals (37%), followed by mallards (21%), gadwalls (20%), northern shovelers (12%), and northern pintails (10%).

Table 1. The number of nests found each year by species and habitat. WW is winter wheat, PC is perennial cover, BWTE is Blue-winged Teal, GADW is Gadwall, MALL is Mallard, NOPI is Northern Pintail, NSHO is Northern Shoveler.

Species	2010		2011		2012	
	WW	PC	WW	PC	WW	PC
BWTE	108	310	28	445	78	364
GADW	104	146	28	141	126	317
MALL	121	184	56	183	104	261
NOPI	122	61	39	136	113	118
NSHO	94	155	20	124	29	96
Total	549	856	171	1,029	450	1,156

The amount of area searched for each habitat varied by year and ranged from about 1,300 to 3,500 hectares in winter wheat and about 2,600 to 4,500 hectares in perennial cover (Table 2). It should be noted that in 2011, nest searching in winter wheat was limited due to the extremely wet spring and flood conditions experienced that season

and our need to search in relatively dry-soil conditions to minimize the amount of damage to the crop and soil.

Table 2. The number of hectares searched in each habitat by year.

Habitat	2010	2011	2012
Winter Wheat	3,497	1,335	2,838
Perennial Cover	2,891	4,549	2,674

We monitored nests on sites that varied widely in terms of their values for basin count and proportion of cropland. The number of basins ranged from 58 to 427 by site with an average of 204 (SD = 66.76). Proportion of cropland by site ranged from 0.08 to 0.89 with an average of 0.51 (SD = 0.18). Nest vegetation density ranged from VOR values of 0 to 12.63 decimeters, but were lower on average ($x = 3.42$, SD = 1.74).

Nest Survival Analysis

Estimated overdispersion for our dataset was 1.32, which was used to adjust AICc scores and variances of model results based on QAICc scores for competing models. Our results supported most, though not all, of our predictions. Many of the covariates were the same across all well-supported models and furthermore, the relationship between any given covariate and daily nest survival was consistent in all well-supported models that included the covariate of interest. All models that were within 7 Δ QAICc units of the top model included species (contained in all models), habitat, year, nest age and wetland basin count. In addition to the covariates supported in all models, we also found support from models within 2 Δ QAICc units of the top model (Table 3) for including (1) an interaction between species and habitat (12 of 15 models), (2) study area (10 of 15

models), (3) nest vegetation density (9 of 15 models), (4) cropland (8 of 15 models), (5) calendar date (3 of 15 models), and (6) a quadratic term for nest age (2 of 15 models).

However, estimated coefficients for covariates that were included in approximately half of the models or less had associated confidence intervals that overlapped zero to at least some degree, preventing us from making strong inference about their importance.

Table 3. Model selection results for DSR of nests, adjusted for overdispersion ($\hat{c}=1.32$).

Model**	QAICc	Delta QAICc	QAICc Weights	Model Likelihood	Num. Par.
Spp*Hab + Study + Crop + VOR	8211.84	0.00	0.05	1.00	17
Spp*Hab + Study + VOR	8212.15	0.31	0.04	0.85	16
Spp*Hab + Crop + VOR	8212.51	0.67	0.04	0.72	16
Spp*Hab + Study	8212.51	0.67	0.04	0.71	15
Spp*Hab + Study + Crop	8212.58	0.75	0.03	0.69	16
Study + Crop + VOR	8212.76	0.92	0.03	0.63	13
Spp*Hab + VOR	8212.86	1.02	0.03	0.60	15
Study + VOR	8213.14	1.30	0.03	0.52	12
Spp*Hab + Study + Crop + VOR + NestAge ²	8213.20	1.37	0.02	0.50	18
Spp*Hab + Study + Crop + Tdate	8213.30	1.46	0.02	0.48	17
Spp*Hab + Study + Tdate	8213.31	1.47	0.02	0.48	16
Spp*Hab	8213.37	1.53	0.02	0.47	14
Spp*Hab + Crop	8213.42	1.58	0.02	0.45	15
Crop + VOR	8213.50	1.66	0.02	0.44	12
Spp*Hab + Study + VOR + NestAge ²	8213.53	1.69	0.02	0.43	17
Spp*Hab + Study + Crop + VOR + Tdate	8213.61	1.77	0.02	0.41	18

**ALL models include: Species, Habitat, Nest Age, Year, and Basin Count; Abbreviated covariates in the model are Spp = Species, Hab = Habitat, Study = Study Area, Crop = Cropland, VOR = Vegetation Density, Tdate = Calendar Date.

Because the relationships between nest DSR and estimated coefficients for each covariate were consistent in all the well-supported models and because all covariates in moderately and highly supported models were included in our top model, we chose to primarily focus on results from our top model. The top model included species, habitat,

nest age, year, study area, basin count, cropland, vegetation density, and an interaction between species and habitat (Table 4).

Table 4. Estimated coefficients of covariates from our top model approximating daily survival rates of nests.

Covariate	β Estimate	Std. Error	95% CI	
			Lower	Upper
Intercept*	3.617	0.178	3.269	3.966
Winter Wheat	0.088	0.125	-0.157	0.333
<i>Species</i>				
Gadwall	0.011	0.087	-0.159	0.182
Mallard	-0.344	0.080	-0.500	-0.188
Northern Pintail	-0.395	0.098	-0.588	-0.202
Northern Shoveler	-0.244	0.091	-0.423	-0.065
<i>Species \times Habitat</i>				
Gadwall \times WW	-0.043	0.170	-0.376	0.291
Mallard \times WW	0.252	0.165	-0.071	0.576
Northern Pintail \times WW	0.427	0.184	0.066	0.787
Northern Shoveler \times WW	0.125	0.194	-0.256	0.506
<i>Year</i>				
2011	-0.225	0.080	-0.383	-0.068
2012	0.117	0.063	-0.007	0.241
Nest Age	0.011	0.003	0.005	0.018
Study Area – NWR	0.144	0.088	-0.028	0.317
Basin Count	-0.002	<0.001	-0.003	-0.002
Cropland	-0.264	0.174	-0.605	0.076
VOR	-0.031	0.018	-0.067	0.005

*Blue-winged teal, perennial cover, 2010, and SCR study area were used as the baseline for the intercept.

In the following sections, we present results for the estimated relationship between each covariate and nest survival and provide examples with point estimates of DSRs for different scenarios to give the reader perspective on the relationships between nest survival and the covariates. When presenting examples, we keep the continuous covariates (i.e., nest age, wetland basin count, cropland, and vegetation density) at their

mean values and the categorical values the same (Species = northern pintail, Habitat = winter wheat, Year = 2012, and Study Area = NWR) unless otherwise stated.

Relationships with Habitat and Species

Although the strength of the relationship between habitat and nest survival varied by species, no species had a point estimate for daily survival in winter wheat below that for perennial cover. We saw the most pronounced effect for northern pintails in winter wheat ($\beta_{\text{NOPI} \times \text{WW}} = 0.427$, SE = 0.184), providing strong evidence that northern pintails had higher nest survival in winter wheat than in perennial cover (Figure 2). For example, northern pintail nests had a daily survival rate (DSR) of 0.95 (95% confidence interval [CI]: 0.92 to 0.96) in winter wheat compared to 0.91 (95% CI: 0.88 to 0.94) in perennial cover. There was evidence that mallards also had higher nest survival in winter wheat than in perennial cover ($\beta_{\text{MALL} \times \text{WW}} = 0.252$, SE = 0.165, Figure 2), but the relationship was not as strong as that estimated for northern pintails. Estimated DSR for mallard nests was 0.94 (95% CI: 0.92 to 0.96) in winter wheat compared to 0.92 (95% CI: 0.89 to 0.94) in perennial cover. There was some evidence that northern shovelers nests also had higher nest survival in winter wheat than perennial cover ($\beta_{\text{NSHO} \times \text{WW}} = 0.125$, SE = 0.195, Figure 2), however the associated confidence intervals for the species by habitat interaction coefficient moderately overlapped zero and somewhat limits the strength of inference for this species. Northern shoveler nests had a DSR of 0.94 (95% CI: 0.91 to 0.96) in winter wheat compared to 0.93 (95% CI: 0.90 to 0.95) in perennial cover. The confidence intervals associated with the estimated coefficients for blue-winged teals and

gadwalls interacting with habitat greatly overlapped zero, providing evidence that DSRs in winter wheat were similar to DSRs in perennial cover (Figure 2). For example, blue-winged teal nests had a DSR of 0.95 (95% CI: 0.92 to 0.96) and 0.94 (95% CI: 0.92 to 0.96) in winter wheat and perennial cover, respectively.

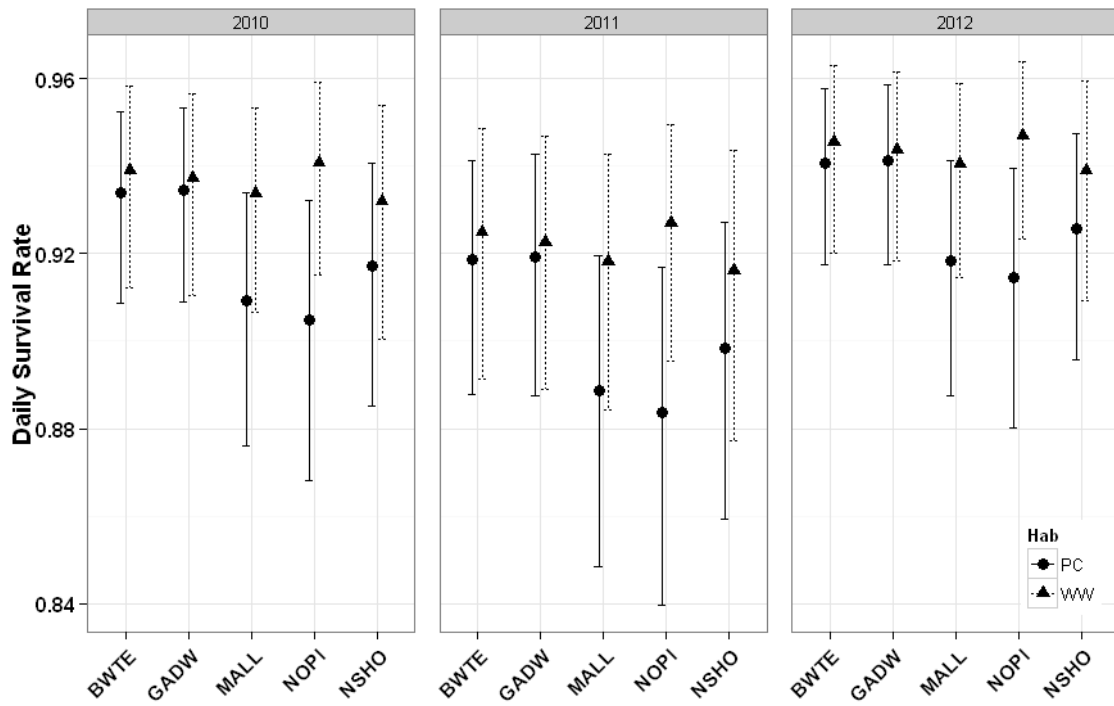


Figure 2. Daily nest survival rates by species and year in winter wheat (WW) and perennial cover (PC). Basin count, nest age, cropland, and vegetation density were held at their mean values.

Relationships with Temporal and Spatial Characteristics

Our results supported some evidence of temporal variation in DSR. Annual DSR was estimated to be highest in 2012 ($\beta_{2012} = 0.252$, $SE = 0.165$), lowest in 2011 ($\beta_{2011} = -0.043$, $SE = 0.170$), and similar between 2010 and 2012 (Figure 2). As an example of the

extent of variation among years, nests in 2012 had a DSR of 0.95 (95% CI: 0.92 to 0.96) compared to a DSR of 0.93 (95% CI: 0.90 to 0.95) in 2011 and 0.94 (95% CI: 0.92 to 0.96) in 2010. As predicted, our results supported a positive relationship between nest age and daily survival rates ($\beta_{\text{NestAge}} = 0.011$, $\text{SE} = 0.003$; Figure 3). For example, nests 5-days old were estimated to have a DSR of 0.96 (95% CI: 0.96 to 0.97), whereas 20-day-old nests were estimated to have a DSR of 0.97 (95% CI: 0.96 to 0.98).

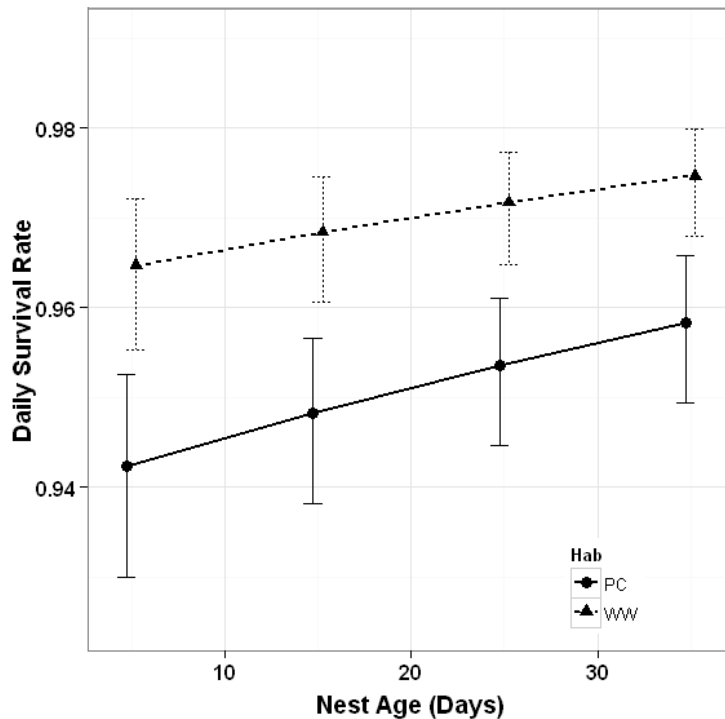


Figure 3. Daily survival rate of nests in winter wheat (WW) and perennial cover (PC) in relation to nest age. We used nests of northern pintails in 2012, in the NWR study area and held basin count, cropland, and vegetation density at their mean values.

As expected, our results also supported inclusion of several spatial sources of variation in models of DSR. We found evidence that DSRs differed between study areas, with DSR estimated to be higher in the NWR study area ($\beta_{\text{NWR}} = 0.144$, $\text{SE} = 0.088$) compared to the SCR study area, although the estimate was not precise enough to permit

strong inference. For example, nests in the NWR study area had a DSR of 0.93 (95% CI: 0.90 to 0.95) and in the SCR study area had a DSR of 0.92 (95% CI: 0.88 to 0.94). Within a study site, estimated DSR varied in relation to the number of wetland basins and the amount of cropland on the site. The estimated relationship between DSR and the number of wetland basins at the 10.4-km² scale was negative ($\beta_{\text{BasinCt}} = -0.002$, SE <0.001; Figure 4). As an example of the extent of variation with the number of basins, at 100 wetland basins in the landscape, DSR was estimated at 0.96 (95% CI: 0.94 to 0.97), at 200 basins in the landscape, DSR was estimated at 0.95 (95% CI: 0.92 to 0.96), and at 300 basins in the landscape, DSR was estimated at 0.93 (95% CI: 0.90 to 0.95).

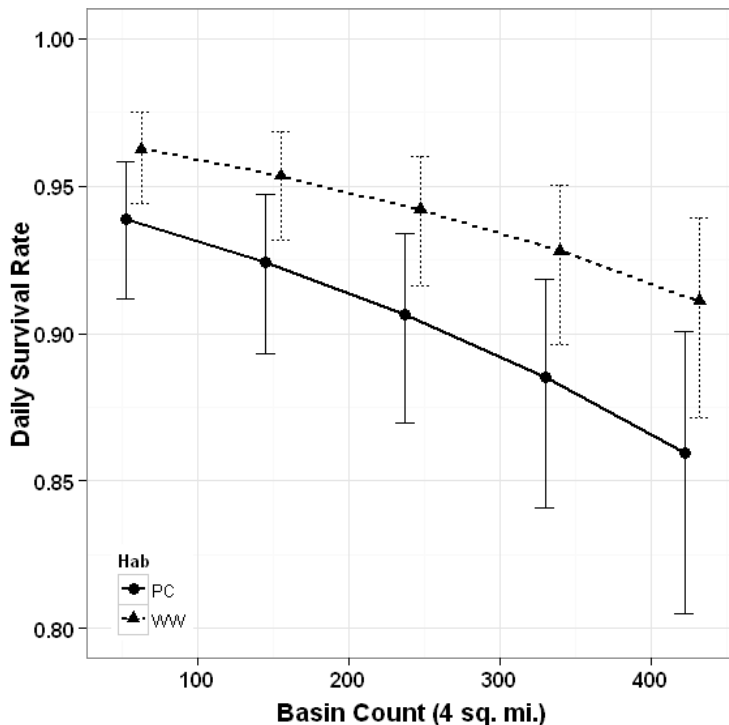


Figure 4. Daily survival rate of nests in winter wheat (WW) and perennial cover (PC) in relation to the number of basins at the 10.4 km² scale. We used nests of northern pintails in 2012, in the NWR study area and held nest age, cropland, and vegetation density at their mean values.

As predicted, our results indicated that DSR decreased as the proportion of cropland on the landscape increased ($\beta_{\text{Crop}} = -0.264$ SE = 0.174; Figure 5). However, the estimates of DSR did not differ much for varying cropland levels and had 95% confidence intervals that overlapped one another substantially. A landscape containing 10% cropland had an estimated DSR of 0.95 (95% CI: 0.93 to 0.97), 50% cropland had an estimated DSR of 0.95 (95% CI: 0.92 to 0.96), and 90% cropland had an estimated DSR of 0.94 (95% CI: 0.92 to 0.96).

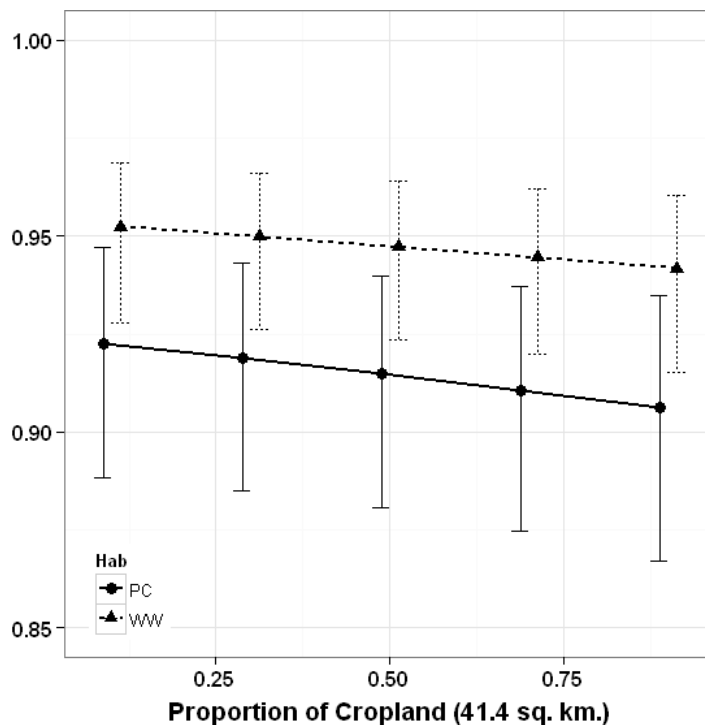


Figure 5. Daily survival rate of nests in winter wheat (WW) and perennial cover (PC) in relation to the proportion of cropland at the 41.4 km² scale. We used nests of northern pintails in 2012, in the NWR study area and held nest age, basin count, and vegetation density at their mean values.

In contrast to our prediction, our results provided some evidence that DSR was lower for nest sites with higher vegetation density ($\beta_{\text{vegDens}} = -0.031$, $\text{SE} = 0.018$) although the 95% confidence interval for the DSR estimates overlapped quite heavily (Figure 6). For example, DSR for vegetation density with a VOR of 1 decimeter was estimated at 0.95 (95% CI: 0.93 to 0.97), for 4 decimeters DSR was estimated at 0.95 (95% CI: 0.92 to 0.96), and for 7 decimeters DSR was estimated at 0.94 (95% CI: 0.91 to 0.96).

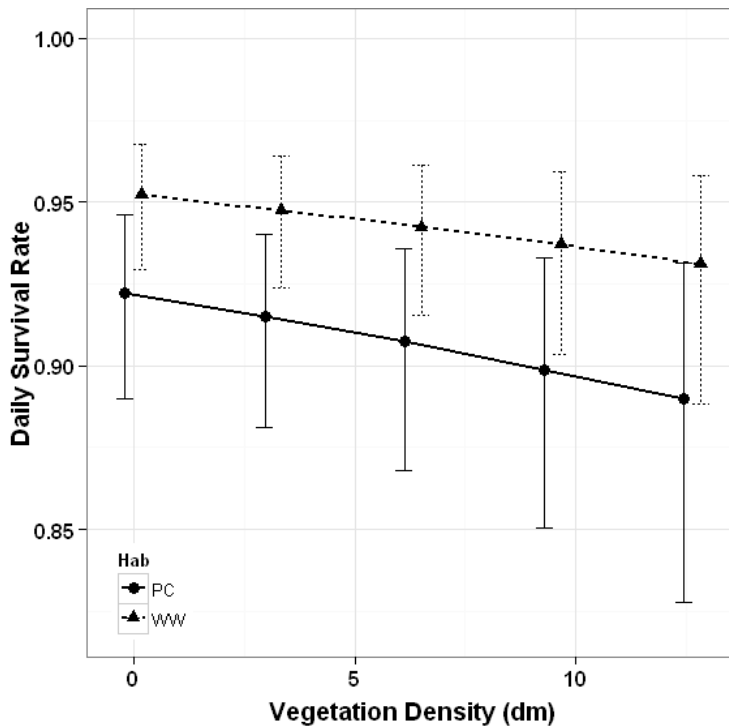


Figure 6. Daily survival rate of nests in winter wheat (WW) and perennial cover (PC) in relation to vegetation density at the nest-site. We used nests of northern pintails in 2012, in the NWR study area and held nest age, cropland, and basin count at their mean values.

Estimates of Nest Success

When examining estimates of 35-day nesting success based on the best-supported model, values for nests in perennial cover ranged from a low of 0.05 for northern pintails in the SCR in 2011 to a high of 0.30 for gadwalls in the NWR in 2012. In winter wheat, values ranged from a low of 0.13 for northern shovelers in the SCR in 2011 to a high of 0.33 for northern pintails in the NWR in 2012. Point estimates of nest success for a given combination of species, study area and year were always higher in winter wheat than in perennial cover (Table 5). The biggest between-habitat difference in nest success estimates was found for northern pintails. Average nest success across years and study areas was ~2.4 times higher in winter wheat than perennial cover habitat for northern pintails (25% [SE = 0.04] vs. 11% [SE = 0.02]), ~1.8 times higher in winter wheat than perennial cover for mallards (21% [SE = 0.03] vs. 12% [SE = 0.02]), and ~1.4 times higher in winter wheat than perennial cover for northern shovelers (21% [SE = 0.04] vs. 14% [SE = 0.02]; Table 5). Nest success was similar between the two habitats for blue-winged teal and gadwall (24% [SE = 0.04] vs. 21% [SE = 0.02] and 23% [SE = 0.04] vs. 22% [SE = 0.03], respectively).

Table 5. Nest success (NS) estimates and associated standard errors (SE) for each species by year and study area.

Species	Year	Study Area	Perennial Cover		Winter Wheat	
			NS	(SE)	NS	(SE)
BWTE	2010	NWR	0.25	(0.02)	0.28	(0.04)
	2011	NWR	0.18	(0.02)	0.21	(0.04)
	2011	SCR	0.14	(0.02)	0.16	(0.04)
	2012	NWR	0.29	(0.02)	0.32	(0.04)
GADW	2010	NWR	0.26	(0.03)	0.27	(0.04)

Table 5 Continued

GADW (cont.)	2011	NWR	0.18	(0.03)	0.20	(0.04)
	2011	SCR	0.14	(0.03)	0.15	(0.04)
	2012	NWR	0.30	(0.03)	0.31	(0.04)
MALL	2010	NWR	0.14	(0.02)	0.25	(0.03)
	2011	NWR	0.09	(0.02)	0.18	(0.03)
	2011	SCR	0.06	(0.02)	0.14	(0.03)
	2012	NWR	0.18	(0.02)	0.29	(0.04)
NOPI	2010	NWR	0.13	(0.03)	0.29	(0.04)
	2011	NWR	0.08	(0.02)	0.22	(0.04)
	2011	SCR	0.05	(0.02)	0.17	(0.04)
	2012	NWR	0.16	(0.03)	0.33	(0.04)
NSHO	2010	NWR	0.17	(0.03)	0.24	(0.05)
	2011	NWR	0.11	(0.02)	0.17	(0.04)
	2011	SCR	0.08	(0.02)	0.13	(0.04)
	2012	NWR	0.21	(0.03)	0.28	(0.05)

Hatched Nests per Hectare

We searched a similar number of hectares in winter wheat and perennial cover (Table 2). We also searched 2,154 hectares of spring wheat in 2010. Although the number of hatched nests per hectare varied by year (Table 6), it was on average 1.8 times higher in perennial cover than in winter wheat (0.135 vs. 0.073, respectively). On the other hand, hatched nests per hectare was on average 6.5 times higher in winter wheat than in spring wheat (0.073 vs. 0.011).

Table 6. Hatched nests per hectare (Ha) in perennial cover, winter wheat, and spring wheat for each year.

	2010		2011		2012	
	Hatched Nests	Hatched Nests/Ha	Hatched Nests	Hatched Nests/Ha	Hatched Nests	Hatched Nests/Ha
Perennial Cover	365	0.126	350	0.077	542	0.203
Winter Wheat	247	0.071	78	0.058	255	0.090
Spring Wheat	23	0.011	NA	NA	NA	NA

DISCUSSION

We studied several features of duck nesting ecology in different agricultural settings and have information that both supports and extends previous findings on the utility of winter wheat as a useful management tool for nesting ducks in the PPR. Two main features were of particular note. First, we found that substantial numbers of ducks nested in winter wheat, which was in striking contrast to the low numbers found in spring-planted wheat. Second, duck nests in winter wheat had survival rates at least as high as those in perennial cover such that the fields of winter wheat produced important numbers of hatched duck nests.

Relationships with Habitat

Although evidence of ducks nesting in fall-seeded crops is limited, it was documented recently in the PPR of Saskatchewan by Devries et al. (2008) and over 25 years ago in the PPR of North Dakota by Duebbert and Kantrud (1987). We were able to provide supporting evidence of all 5 common upland-nesting ducks (*Anas* spp.) nesting in winter wheat within the PPR of North and South Dakota based on a larger sample size. Our estimates for winter wheat were slightly lower than those reported by previous studies (Duebbert and Kantrud 1987, Devries et al. 2008), but our estimates for perennial cover were comparable to those from recent studies that were carried out in a similar area of the PPR of North Dakota (Stephens et al. 2005, Walker et al. 2013). To our knowledge, ours is the only study to explicitly compare survival rates for nests in winter wheat with those in perennial cover and we found evidence that nest survival was at least

as high in winter wheat as perennial cover, and for several species, the survival rate was higher in winter wheat.

We speculated several reasons why nest survival was higher for some species in winter wheat than in perennial cover. First, previous work has shown predation to be the highest cause of nest loss for waterfowl (Sargeant and Raveling 1992, Greenwood et al. 1995, Sovada et al. 2001, Emery et al. 2005, Pieron and Rowher 2010) and evidence at the nests suggested this was also the case for both habitats in our study; however we suspect the pressures from the predator communities within each habitat might be different. Mammals are the main predators of waterfowl nests in the PPR (Sargeant and Raveling 1992, Sargeant et al. 1993); however waterfowl nests are not the main component of most mammalian predator's diets (Snead and Hendrickson 1942, Greenwood 1981, Lampe 1982, Sargeant et al. 1986, Greenwood et al. 1999, Sovada et al. 1999). Most duck-nest predators are generalists and consume anything from arthropods and other insects to small mammals and birds. Monocultures of winter wheat might be less attractive to foraging predators due to the decrease in diversity and abundance of potential prey (small mammals and insects) associated with monocultures (Flowerdew 1997, Benton et al. 2003, Smith et al. 2005). Further, although we accounted for the number of wetland basins within 10.36 km² around the site, wetland density might be less within winter wheat fields due to agricultural practices like draining. If so, such sites might attract fewer mammal predators, given that mammals have been shown to prefer wetland edges and wet meadows that contain many prey species (Greenwood et al. 1999, Larivière and Messier 2000, Phillips et al. 2004).

Second, given our evidence that nest density was lower in winter wheat, it is also possible that density-dependent predation rates could partly be responsible for differences in habitat-specific nest survival rates. However, extensive uncertainty surrounds the topic of density-dependent predation for waterfowl nests (Major and Kendal 1996, Ackerman 2002). Some studies have reported strong evidence (Sugden and Beyersbergen 1986, Gunnarsson and Elmberg 2008), while others have reported no evidence (Ackerman et al. 2004, Padyšáková et al. 2010, Ringelman et al. 2012). Additionally, most studies are solely based on artificial nests, which have been criticized for potential inaccurate representation of predation rates on natural nests (Major and Kendal 1996, Butler and Rotella 1998, Zанette 2002). Without more evidence that would require extensive research to monitor nests as well as the predator communities more intensely in different habitat types, we cannot determine how much of a factor density-dependent predation is in our study. We also acknowledge the difficulty in obtaining this information and the fact that there is still much to be learned on the topic of density-dependent nest predation in duck populations.

Relationships with Species

Consistent with previous literature (Stephens et al. 2005, Walker et al. 2013) and our expectation, our study found evidence of species differences in nest survival rates. We found mallards and northern pintails to have the lowest nest survival estimates and gadwall and blue-winged teal to have the highest rates. Differences in nest survival rates between winter wheat and perennial cover depended on species, with the most noticeable

difference in estimates for northern pintails. Nests of northern pintails in winter wheat were about 2.4 times more likely to succeed than those in perennial cover. Nest success estimates ranged from 0.05 to 0.16 (SD = 0.049) in perennial cover and were similar to estimates reported by Guyn and Clark (2000). In contrast, our estimates of nest success in winter wheat were substantially higher, ranging from 0.17 to 0.33 (SD = 0.074). Given that northern pintails typically have low nest success (Klett et al. 1988) and are known to prefer cropland habitat (Higgins 1977, Klett et al. 1988, Greenwood et al. 1995), where reported nest success estimates have been extremely low in spring-seeded crops (Milonski 1958, Klett et al. 1988, Greenwood et al. 1995), winter wheat could have important management implications for this species. Further, northern pintail populations, unlike other upland-nesting duck populations, have not recovered since the sharp decline in all duck populations in the 1950s. Winter wheat has the potential to aid perennial cover in recruitment of more ducklings to the population.

We also found evidence of habitat-based differences in nest survival for mallards and northern shovelers, but the differences were not as strong as that found for northern pintails. Nests in winter wheat were about 1.8 and 1.5 times more likely to succeed than nests in perennial cover for mallards and northern shovelers, respectively. Given that mallards commonly have one of the lowest reported estimates for nest success of the common upland nesting ducks (Greenwood et al. 1995, Stephens et al. 2005, Pieron and Rowher 2010), winter wheat could also be a valuable habitat for nesting mallard populations. Nest survival for blue-winged teal and gadwall was also estimated to be higher in winter wheat than in perennial cover, but the estimated differences were small.

Regardless, we found that nest survival in winter wheat was at least as good as in perennial cover, and our estimates of nest success in winter wheat (Table 5) were almost always greater than the recommended nest success rates required to maintain the population (15% for northern pintails and mallards, Cowardin et al. 1985, and 20% for all other species, Klett et al. 1988). On the other hand, our nest success estimates for perennial cover (Table 5) only met the recommended values approximately half the time, further supporting the idea that winter wheat can be a valuable management tool for producing sustainable populations of ducks.

Relationships with Temporal and Spatial Characteristics

Temporal and spatial variation has been documented widely in duck-nest survival studies throughout the PPR. Consistent with previous studies, we also found support for multiple temporal and spatial characteristics in our study. As expected due to variable annual conditions in the PPR (Walker et al. 2013), nest survival varied during the study with survival highest in 2012 and lowest in 2011. As we predicted and consistent with results of earlier studies (Klett and Johnson 1982, Stephens et al. 2005, Grant and Shaffer 2012, Thompson et al. 2012, Walker et al. 2013), we also found that nest survival increased with nest age. We are unsure, however, about the underlying mechanism. It could be the result of modified hen behavior at the nest, such that females increase the amount of time spent at the nest (Caldwell and Cornwell 1975, Afton 1979, Klett and Johnson 1982) and/or allow predators to approach more closely as incubation progresses (Mallory and Weatherhead 1993, Forbes et al. 1994). The prolonged presence of the hen

at the nest could decrease the number of visual cues that might attract predators or be a physical deterrent for some predators (Thompson and Raveling 1987, Ringelman and Stupaczuk 2013). However, it is also possible that the pattern seen was due to heterogeneity in nest survival whereby nests of lower quality tend to fail at higher rates early on such that the nests that survived to older ages would tend to have higher inherent survival rates (Cam et al. 2002), creating a false perception of the relationship between survival and nest age (Vaupel and Yashin 1985). To determine the underlying mechanism, behavioral studies and/or models including individual heterogeneity would be required, which can be problematic for studies where not all nests are found at initiation (Rotella et al. 2007).

Our results also supported several sources of spatial variation in nest survival. Based on the work by Stephens et al. (2005), we took into account different spatial scales and found most, but not all, of our hypotheses supported. Consistent with our prediction and results of previous studies (Stephens et al. 2005, Thompson et al. 2012), we found that nest survival decreased with the number of wetland basins in the landscape. This is counterintuitive given that ducks have been shown to prefer nesting in areas of greater wetland density (Johnson and Grier 1988, Cowardin et al. 1995, Krapu et al. 1997, Bloom et al. 2013). However, wetlands are an extremely productive habitat associated with high levels of primary productivity (van der Valk 1989) and consistent with the hypothesis of Stephens et al. (2005), will likely also support a greater number of predators. Furthermore, some duck-nest predators have been shown to prefer wetlands and/or wetland edges when foraging (Crabtree et al. 1989, Sargeant et al. 1998, Lariviere

and Messier 2000, Kuehl and Clark 2002, Phillips et al. 2003, Phillips et al. 2004) and nests on sites with high wetland density can reasonably be expected to be closer to wetlands and more vulnerable to predators, on average, than they would be on drier sites.

As predicted, we found nest survival to be negatively related to the proportion of cropland on the landscape; however, the estimated change in nest survival over the range of cropland proportions studied was modest. A few studies have found no relationship with cropland (Howerter 2003, Arnold et al. 2007, Walker et al. 2013), however numerous studies have found a negative pattern (Boyd 1985, Greenwood et al. 1995, Reynolds et al. 2001, Stephens et al 2005, Drever et al. 2007, Devries and Armstrong 2011, Thompson et al. 2012, Bloom et al. 2013), which is in accordance with our results. The conversion of grassland to cropland has been associated with habitat fragmentation (Gehring and Swihart 2003), which likely affects foraging patterns of predators (Stephens et al. 2005). Some duck-nest predators reach their highest densities in highly fragmented landscapes (Donovan et al. 1997), and it is believed that smaller patches of habitat have a positive effect on foraging efficiency of predators (Sovada et al. 2000, Phillips et al. 2003). Differences in abundance and distribution of alternative prey or the types of predator communities associated with different levels of cropland are not something we addressed with this study, but could also play a role in the pattern we see with cropland.

Contrary to our prediction and evidence from previous studies conducted in other regions (Warren et al. 2008, Thompson et al. 2012, Bloom et al. 2013), we found some evidence of a negative relationship between vegetation density at nest sites and nest survival. Although this was unexpected, the relationship was modest (see Table 4 and

Figure 6) and numerous studies have found no evidence for a relationship between nest survival and vegetation density (Ackerman 2002, Koons and Rotella 2003, Stephens et al. 2005, Jimenez et al. 2007, Walker et al. 2008). We suspected that thicker vegetation would decrease foraging efficiency of predators and conceal nests better (Sugden and Beyersbergen 1987); however mammalian predators rely more heavily on olfaction cues rather than visual cues (Conover 2007). Jimenez et al. (2007) hypothesized that such a relationship could be caused if both nesting hens and predators are attracted to patches of thicker vegetation leading to higher predation rates for nests in thicker cover.

Hatched Nests per Hectare

Our estimates of hatched nests per hectare provide an integrated assessment of nest density and nest survival in different habitat settings. Winter wheat produced at least half as many nests as perennial cover and 6.5 times as many nests as spring wheat, providing good evidence that winter wheat can produce a substantial number of duck nests. Winter wheat offers the opportunity for managers to present farmers with an alternative to spring-seeded crops that benefits both waterfowl and the farmer as a valuable cash-crop.

MANAGEMENT IMPLICATIONS

Managers are constantly looking for ways to increase nesting cover in the landscape. In the face of declining CRP acres and the push for farmers to convert more land to cash-crops, winter wheat offers a solution that could help balance the habitat needs of nesting waterfowl with modern agriculture. Planting winter wheat offers some advantages to farmers over exclusively planting spring-seeded crops. It allows the work load to be spread between the fall and spring and provides the advantage of having some fields already planted during extremely wet spring conditions, when spring-seeding can be difficult. Winter wheat also offers economic benefits with a lower production cost and higher yield on average than spring wheat. It also prevents soil erosion over winter and competes well with weeds in the spring once it is established (Devries and Guyn 2013).

Although winter wheat offers some advantages to farmers, it also presents some challenges. Conditions need to be right when planting in the fall for the seed to germinate. Also, harsh conditions typical of winters in North and South Dakota can decrease seed survival. However, over the last decade through research and collaborations, new cold-tolerant and disease-resistant varieties of winter wheat have been developed and proven to be very successful in the PPR. Another challenge with winter wheat is altering farming traditions and beliefs. Although planting everything in the spring is a long-held tradition, the agronomic benefits should overcome this barrier (Devries and Guyn 2013).

In the highly cropped landscape of the PPR, winter wheat offers a conservation tool to aid wildlife managers in the struggle to balance the habitat needs of duck

populations with the needs of agriculture to produce more cash-crops. Winter Cereals: Sustainability in Action (WCSIA) is a program recently initiated by Ducks Unlimited and Bayer Crop Science to increase research and education on winter cereals with the goal of building a stewardship model to improve agricultural productivity while maintaining habitat for wildlife. WCSIA has worked with universities to develop stronger winter wheat varieties and with landowners to provide education on the benefits of planting winter cereals and demonstrations to promote interest (Adair 2014). We encourage wildlife managers to consider the benefits of winter wheat when designing programs to increase nesting habitat in the landscape, however we caution that winter wheat should be used as an aid to existing perennial cover in the landscape and not as a replacement.

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