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BREEDING FIDELITY AND LANDSCAPE EFFECTS ON DISTRIBUTION OF MALLARDS AND DUCK BROODS IN THE NEBRASKA SANDHILLS

by

Zachary J. Cunningham

A THESIS

Presented to the Faculty of
The Graduate College at the University of Nebraska
In Partial Fulfillment of Requirements
For the Degree of Master of Science

Major: Natural Resource Sciences

Under the Supervision of Professor Larkin Powell

Lincoln, Nebraska
August, 2011
I investigated aspects of mallard (*Anas platyrhynchos*) breeding ecology in the Nebraska Sandhills during 2007-2008. Previous work in this region suggests that nest success is low for a large area of intact grassland such as the Sandhills. My goal was to conduct a local-scale examination of age distribution and return rates of mallards, and a large-scale examination of brood distribution in the Sandhills region as a whole. This information will help explain factors contributing to the low nest success previously observed, determine relationships between landscape composition and spatial distribution of waterfowl in the Sandhills, and predict productivity and abundance of ducks in the Sandhills from a spatial model.

I used decoy traps to capture mallard ducks prior to nesting to ascertain age ratios and return rates for captured birds. I captured and banded 820 unique ducks representing 6 species during 2005-2008. Age distribution (SY:ASY) of mallards in 2007 was 0.9:1 for males and 6:1 for females and 0.8:1 for males and 2.3:1 for females in 2008. Mallard
recapture rate was 7.4% and recovery rate was 30%. Mallard survival was 79.5% with a fidelity rate of 61.8%.

I conducted road-count brood surveys consisting of three survey routes extending across the Sandhills. These presence/absence surveys were used to document the abundance and distribution of duck broods in the Nebraska Sandhills. Nine different duck species broods were observed on the survey routes in 2008. The 4 most common duck species broods observed on the survey routes were the mallard, blue-winged teal, gadwall (A. strepera), and redhead (Aytha americana).

Results from the brood survey allowed me to produce a thunderstorm map predicting the probability of brood occurrence across the Sandhills. Analysis of the thunderstorm map suggests that waterfowl productivity is at its highest in the eastern Sandhills. This map will be one tool to help managers identify high priority wetland habitat that can be protected through various habitat conservation strategies by private or governmental agencies.
ACKNOWLEDGEMENTS

There are many people I would like to acknowledge for their contribution to this project. Funding was provided by the Nebraska Game and Parks Commission, the University of Nebraska-Lincoln, and the Sandhills Task Force. The University of Nebraska, Barta Brothers Ranch was kind enough to provide housing for me and my decoy hens during the field season.

I would like to thank the fine folks at the Central Flyway Wing Bee in Hartford, Kansas who not only helped me refine my skills at identifying and aging waterfowl wings, but who spot-checked wings from my birds in 2008.

I am especially thankful to the Sandhills landowners who allowed me to conduct my research on their land. Special thanks go to Rich, Laura, and Caleb Lackaff, whose kindness and hospitality are unmatched, and who more then once pulled me out of the mud. My research would not have been possible without them.

Thank you to my committee members: Larkin Powell, Mark Vrtiska, and Scott Stephens, as well as Johann Walker, Nick Lyman, Randy Stutheit, Rich Walters, Ted LaGrange and Andy Bishop, whose patience, guidance and expertise were greatly appreciated. Dr. Powell was the best advisor a young wildlife student could ask for; he always had wise answers to my many questions.

I would like to thank the many technicians and volunteers who helped collect data during my field seasons. There were many challenges and hardships during our work; from late April blizzards that froze our traps shut, to the rough Sandhills roads that took a brutal toll on our work vehicles; their hard work and companionship helped turn long
days on the windy prairie into lifelong memories. I have developed friendships with several of these dedicated waterfowl enthusiasts and although we have gone off to different corners of the world, we gather at the study site each spring to chase wild turkeys and reminisce about our time as the “duck hunters”.

Thank you to my friends and family, who not only supported me and put up with my absence during my many field seasons, but who always lent a hand (or sympathetic ear) so I could reach my goal.

To my daughter Lauren, thank you for keeping me grounded to what is really important in life.

Finally, I would like to thank my wife Jen for getting me started on my career path. She always believed in and aided me however she could, whether that meant proofreading my work late at night or helping me trap ducks, without her constant support, I would have never succeeded.
# TABLE OF CONTENTS

ABSTRACT ............................................................................................................. II

ACKNOWLEDGEMENTS ....................................................................................... IV

TABLE OF CONTENTS ......................................................................................... VI

LIST OF TABLES ................................................................................................... VIII

LIST OF FIGURES ................................................................................................ X

CHAPTER 1: AGE RATIOS, FIDELITY, AND SURVIVAL OF BREEDING

MALLARDS IN THE NEBRASKA SANDHILLS ......................................................... 1

  ABSTRACT: ........................................................................................................ 1

INTRODUCTION .................................................................................................... 2

METHODS ............................................................................................................. 5

  STUDY AREA ................................................................................................... 5

  STUDY DESIGN ............................................................................................. 6

TARGET SPECIES ............................................................................................... 7

SAMPLING METHODS ......................................................................................... 8

STATISTICAL ANALYSIS .................................................................................. 10

RESULTS ............................................................................................................. 12

  CAPTURE DATA ............................................................................................. 12

  PARAMETER ESTIMATES ........................................................................... 13

DISCUSSION ....................................................................................................... 14

  MALLARD AGE ............................................................................................ 14

  FIDELITY TO THE SANDHILLS ................................................................. 19
MANAGEMENT IMPLICATIONS .......................................................... 20

ACKNOWLEDGEMENTS ............................................................... 23

LITERATURE CITED ..................................................................... 24

CHAPTER 2: LANDSCAPE EFFECTS ON DISTRIBUTION OF DUCK BROODS
IN THE NEBRASKA SANDHILLS ..................................................... 44

ABSTRACT: .................................................................................... 44

INTRODUCTION ............................................................................ 46

METHODS .................................................................................... 47

STUDY AREA .................................................................................. 47

STUDY DESIGN ............................................................................. 50

TARGET SPECIES .......................................................................... 50

SAMPLING METHODS ................................................................. 51

STATISTICAL ANALYSIS ............................................................. 52

RESULTS ....................................................................................... 56

BROOD SURVEYS ......................................................................... 56

LANDSCAPE COVARIATES AND MODELS .................................... 57

DISCUSSION ................................................................................ 58

SURVEY RESULTS ........................................................................ 58

THUNDERSTORM MAP ............................................................... 61

MANAGEMENT IMPLICATIONS .................................................... 63

ACKNOWLEDGEMENTS .............................................................. 66

LITERATURE CITED ..................................................................... 66
LIST OF TABLES

Chapter 1.

Table 1. Species list of ducks observed on the Nebraska Sandhills study area during spring breeding seasons 2005-2008 ........................................ 31

Table 2. The number of unique individual ducks banded per species on the Nebraska Sandhills study area during spring breeding seasons 2005-2008 .................................................................................................................. 32

Table 3. Distribution of band recoveries (%) from mallards banded on the local-scale study site in Rock County in the Nebraska Sandhills, 1 April 2005 through 1 April 2009, as reported to the Bird Banding Lab ........................................................................................................................................... 33

Table 4. Top ten models showing mallard survival, fidelity, return rate, and recovery probabilities observed in the Nebraska Sandhills during 2005-2008. Models are listed in order of support. Models with larger AIC weights ($w_i$) and lower δAIC values have more support. Models shown have $w_i > 0.03$. and $k$ is the number of parameters in each model ........ 34

Table 5. Survival, recapture, recovery, fidelity estimates and associated 95% confidence intervals for mallards banded during 2005-2008 in the Nebraska Sandhills. Parameters identified are from model # 3 (Table 4) ........................................................................................................................................ 35
CHAPTER 2.

**TABLE 1.** The six landcover indices and associated habitats selected from the Sandhill landcover layer as provided by the Rainwater Basin Joint Venture. Each landcover index includes ≥1 specific habitat types, and some habitat types appear in >1 index ................................................................. 72

**TABLE 2.** Species list of ducks observed on the Nebraska Sandhills survey routes, 2008 .......................................................... 73

**TABLE 3.** Mean, standard deviation, and model averaged estimates for the six covariates estimated from brood survey transects conducted in the Nebraska Sandhills during August 2008. Mean and standard deviation represent the percent cover of 52 segments along the 517 km transects ................................................................. 74

**TABLE 4.** Top nine models describing probability of occurrence of duck broods observed in the Nebraska Sandhills during August 2008. Models are listed in order of support. Models with larger AIC weights ($w_i$) and lower ΔAIC values have more support. Models shown have $w_i > 0.01$, and $k$ is the number of parameters in each model. Thirteen models with $w_i < 0.01$ are not shown; null model $w_i = 0.008$ ........................................ 75
LIST OF FIGURES

CHAPTER 1.


FIGURE 2. LOCATION OF DECOY TRAP SITES FOR THE LOCAL-SCALE EXAMINATION OF AGE DISTRIBUTION AND RETURN RATES OF MALLARDS IN THE NEBRASKA SANDHILLS, 2007-2008 .............................................................. 37

FIGURE 3. NUMBER OF INDIVIDUAL MALE AND FEMALE MALLARDS BANDED DURING 2005-2008 IN THE NEBRASKA SANDHILLS .............................................................. 38

FIGURE 4A-B. COMPARISON OF SECOND-YEAR (SY) AND AFTER SECOND-YEAR (ASY) FEMALE (A) AND MALE (B) MALLARDS CAPTURED DURING 2007-2008 IN THE NEBRASKA SANDHILLS ........................................................................ 39

FIGURE 5. COMPARISON OF SECOND-YEAR (SY) AND AFTER SECOND-YEAR (ASY) FEMALE MALLARDS COLLECTED OUTSIDE THE STUDY AREA AS A BIAS COMPARISON DURING 2008 IN THE NEBRASKA SANDHILLS .............................................................. 40

FIGURE 6. COMPARISON OF BAND RECOVERIES OF FEMALE AND MALE MALLARDS FROM BIRDS BANDED ON THE SANDHILLS STUDY LOCATION 2005-2008 ......................... 41

FIGURE 7. LOCATION OF BAND RECOVERIES FROM MALLARDS BANDED ON THE LOCAL-SCALE STUDY SITE IN ROCK COUNTY IN THE NEBRASKA SANDHILLS, 2005-2008. FIGURE CREATED BY DUCKS UNLIMITED USING MY BANDING DATA ......... 42
FIGURE 8. NUMBER OF INDIVIDUAL MALE AND FEMALE MALLARDS RECAPTURED DURING 2005-2008 IN THE NEBRASKA SANDHILLS ..................................................... 43

CHAPTER 2.

FIGURE 1. LOCATION OF BROOD SURVEY ROUTES IN THE NEBRASKA SANDHILLS, 2008 ........................................................................................................................................ 76

FIGURE 2. SURVEY ROUTE DATASHEET CREATED FOR DUCK BROOD SURVEYS CONDUCTED IN THE NEBRASKA SANDHILLS, AUGUST 2008. POND NUMBER 1 IS AN EXAMPLE SHOWING THE OBSERVATION OF 3 DUCKS AND NO BROODS, WITH X’S REPRESENTING DUCK LOCATIONS ON THE WETLAND .............................................................. 77

FIGURE 3. COMPOSITION OF DUCKS SPECIES BROODS OBSERVED DURING BROOD SURVEYS IN THE NEBRASKA SANDHILLS, 2008 ................................................................. 78

FIGURE 4. LOCATION OF POSITIVE BROOD OBSERVATIONS ON THE O’NEILL SURVEY ROUTE IN THE NEBRASKA SANDHILLS, 2008. SOME BROOD LOCATIONS REPRESENT MULTIPLE BROOD OBSERVATIONS ................................................................. 79

FIGURE 5. LOCATION OF POSITIVE BROOD OBSERVATIONS ON THE WOOD LAKE SURVEY ROUTE IN THE NEBRASKA SANDHILLS, 2008. SOME BROOD LOCATIONS REPRESENT MULTIPLE BROOD OBSERVATIONS ................................................................. 80

FIGURE 6. LOCATION OF POSITIVE BROOD OBSERVATIONS ON THE LAKESIDE SURVEY ROUTE IN THE NEBRASKA SANDHILLS, 2008. SOME BROOD LOCATIONS REPRESENT MULTIPLE BROOD OBSERVATIONS ................................................................. 81

FIGURE 7. THUNDERSTORM MAP PREDICTING PROBABILITY OF OCCURRENCE OF DUCK BROODS IN THE NEBRASKA SANDHILLS, BASED ON BROOD SURVEYS COMPETED IN
AUGUST 2008. SPATIAL MODEL WAS CONSTRUCTED USING THE SIX LANDSCAPE
INDICES AND MODEL AVERAGED COEFFICIENTS IN TABLE 3 .......................... 82
CHAPTER 1: Age ratios, fidelity, and survival of breeding mallards in the Nebraska Sandhills

Abstract:

Waterfowl managers often associate large tracts of intact grassland with high duck nest success because these areas often minimize the impacts of predators. However, recent investigations in the Nebraska Sandhills suggests otherwise. I conducted a local-scale examination of age distribution, fidelity, and survival rate of mallards trapped and banded in the Sandhills to help explain low nest success observed in this area. I recorded age ratios of decoy trapped mallards and used banding data to estimate mallard fidelity, survival, band recovery rates, and recapture rates of mallards banded on the study site over a four-year period. My target species was the mallard (A. platyrhnchos) because of its abundance on the study site and because it is the primary duck species used in making waterfowl management decisions. Age distribution (SY:ASY) of mallards in 2007 was 0.9:1 for males and 6:1 for females and was 0.8:1 for males and 2.3:1 for females in 2008. My recapture rate estimate for mallards was 0.074 (95% CI: 0.033 - 0.158), and the recovery rate estimate was 0.300 (95% CI: 0.156 - 0.497). Mallard survival rate was 0.795 (95% CI: 0.609 - 0.906) with a fidelity rate of 0.618 (95% CI: 0.283 - 0.868). The high proportion of young female mallards observed could be one cause of the low nest success and high nest abandonment previously observed.

High survival and apparent influx of young females appears to keep this population stable in the face of low productivity and significant emigration. My study

suggests that managers may be able to use age ratios to gradually assess an areas potential for productivity, and it is likely that information gained as a result of this study will apply to similar areas.

The Sandhills population of mallards appears to be a loosely defined population with large numbers of SY birds, apparently coming from other areas to breed, as large numbers of birds do not return to the Sandhills to breed in subsequent years. This is more evidence for the continued need for flyway-wide monitoring and management on larger scales than focusing solely on individual states. However, it is also evident that small-scale dynamics, such as those observed in the Sandhills may contribute to the complex dynamics of larger flyway-wide populations of mallards, and should not be overlooked.

INTRODUCTION

Managers often attempt to determine factors (e.g., female breeding condition, survival, fidelity) that affect nest survival and recruitment and manipulate or conserve habitat in an attempt to improve nest success on a landscape scale (Johnson et al. 1992, Cowardin et al. 1995). Recent advances in band/recapture models (Doherty et al. 2002), may allow managers of local or regional breeding populations to estimate these same factors without the use of traditional nest searching or large scale banding studies.

Localized decoy trapping and banding, combined with careful examination of characteristics of breeding female parameters can be used to estimate fidelity, survival, recapture, and recovery rates (White and Burnham 1999). These parameters can provide demographic information, trends that can lead managers to better target areas for land
acquisition or habitat improvement in the management of local waterfowl breeding populations.

I studied a regional mallard (A. platyrhynchos) population in the Sandhills of Nebraska. The Sandhills comprise the largest continuous expanse of native grassland remaining in North America, an area of approximately 5,179,976 hectares interspersed with more than 404,685 ha of wetlands (LaGrange 2005). This combination of grasslands and abundant wetlands makes the Sandhills important to nesting ducks; particularly mallards, blue-winged teal (A. discors), and gadwall (A. strepera). Current population trends of breeding ducks in the Sandhills appear stable, and estimates from this region could exceed 275,000 in some years (Vrtiska and Powell 2011).

Large tracts of intact grassland such as the Sandhills are often associated with high duck nest success, because these areas minimize the impacts of predators on ground-nesting birds (Cowardin et al. 1985, Dufor and Clark 2002, Hoekman et al. 2002, Stephens et al. 2005). In contrast to this prediction, the Sandhills region appears to support relatively low rates of nest survival (Glup 1986, Walker et al. 2008). During 2005 and 2006, a radio-telemetry study was conducted to determine the nest success rates of female mallards in the Sandhills (Walker et al. 2008), using research techniques as described by Klett et al. (1986). Data collected from this study suggested that the proportion of nesting success was very low (0.03), but 22-week hen survival during the breeding season was relatively high (0.84) when compared with other studies (Blohm et al. 1987, Sargeant and Raveling 1992, Devries et al. 2003, Brasher et al. 2006). My
study was designed as a follow up to Walker et al. (2008) to provide additional demographic data.

Traditionally, successful females are known to exhibit a higher rate of returning to the study site (fidelity) than unsuccessful females (Lokemoen et al. 1990b), an artifact often associated with female age and experience. Young (SY) female mallards have been shown to be less successful at nesting than older (ASY) birds (Krapu and Doty 1979, Curio 1983) and have been shown to have a higher breeding season survival because of a lower reproductive investment (Cowardin et al. 1985, Dufour and Clark 2002, Hoekman et al. 2002).

Walker et al. (2008) indicated that age of captured and radio-marked females was skewed towards young or second-year (SY) females (87%) when compared to previous studies (Reynolds et al. 1995, Dufour and Clark 2002), but did not investigate fidelity. I hypothesized that a higher proportion of SY females could be responsible for the lower than expected nest success observed by Walker et al. (2008).

Additionally, male mallards banded by Walker et al. (2008) during the 2005 study were recaptured at a higher than expected rate during the 2006 trapping season, given the estimates of low nesting success, skewed age ratios, and typical pairing behavior of mallards. However, Walker et al. (2008) could not provide band analyses of their 2-year data set. The model framework used by Doherty et al. (2002) would allow investigation of aspects of mallard breeding ecology on the same study site as Walker et al. (2008). These analyses could help explain the observed low nest success and provide insight for managers of local populations of mallards.
My goal was to investigate aspects of mallard breeding fidelity in the Nebraska Sandhills. My objectives were to: (1) trap and examine age ratios of mallards breeding in the Sandhills, (2) examine recovery distributions from banded mallards, (3) examine survival and fidelity from band recovery and recapture analyses for mallards banded in the Sandhills.

METHODS

Study Area

The Nebraska Sandhills can be described as a patchwork of wetlands and sand dunes now stabilized by grass (Bleed and Flowerday 1990). This rich mix of wetland types and grasslands is attractive to breeding and nesting waterfowl (Bellrose 1980). Land disturbance in this area is due primarily to settlement, grazing, roads, and to lesser extent, cropland. Most of this region consists of privately-owned ranchland used for beef production (Novacek 1989, LaGrange 2005). Despite some fragmentation due to roads and farmstead tree lines, the grasslands of the Sandhills are relatively intact (Bleed and Flowerday 1990). Several mini-ecosystems exist in the Sandhills including savannas, ephemeral wetlands, fens, and blowouts; with dunes exceeding 100m in height (Bleed and Flowerday 1990). This unique area is host to a diverse mixture of plant and wildlife. Historically, fire played a major role in maintaining Sandhill ecosystems, but due to current range practices this is no longer the case (Bleed and Flowerday 1990).

The study area for the local-scale examination of age distribution and return rates was positioned almost entirely on privately-owned ranchland located approximately 24 km south of Bassett, Nebraska (42° 20' N, 99° 29' W) and encompassed 26,347 ha (Figure
1). Land-cover of the study area was composed of 69% native grassland, 14% hayland, 11% wetlands, 1% cropland, and 5% other classes (Walker et al. 2008).

The study area was typical of the eastern Sandhills in terms of its climate, land-use, and plant community. Annual precipitation on the study area averages 51cm-58cm and an average summer temperature ranged from 19.4ºC to 23.9 ºC (Bleed and Flowerday 1990). I chose this location because: (1) it is the same study site used by Walker et al. (2008), (2) of the abundance of waterfowl in the area, (3) there is an intricate network of wetlands and intact grasslands in the area, and (4) most of the area is privately-owned ranchland, which is representative of the area. The habitat consisted primarily of temporary wetlands, wet meadows, sandy to choppy-sand dunes, mixed-grass prairie and overall, represents the Sandhills as a whole. While there are limited agricultural row-crops, cattle grazing and haying are the predominate land-use practices in the area. Duck densities in this area appeared similar to other areas of the Sandhills (Nebraska Game and Parks Commission [NGPC], unpublished data).

Study Design

My study was designed to sample an extensive wetland complex at the same study site as Walker et al. (2008) in the Nebraska Sandhills. I used decoy traps to capture female mallards prior to nesting during 2005-2008. Placement of decoys traps within my study site was based on several factors, including: (1) landowner permission, (2) distance between wetlands, (3) accessibility from roads, (4) observed use by breeding pairs, and (5) wetland availability on the landscape. I attempted to place decoy traps across a variety of wetland types and locations on the 26,347 ha study area in an attempt to
eliminate bias and to ensure my sampling method was representing the Sandhills as a whole (Figure 2). I set 24 traps at different locations each day, resulting in >200 total trapping locations during the study. In some cases, multiple traps were used at a single site if mallard pairs avoided the trap. I recorded UTM coordinates for each trap site. I trapped 7 days a week from 1 April – 7 June for a total of 67 days each year.

Walker et al. (2008) observed captured female mallards exhibited a high ratio of SY birds. One possible explanation for this is that SY birds are more susceptible to trapping than older, ASY birds. To test this hypothesis, I continued trapping at the original capture locations (Walker et al. 2008) while a random sample of female mallards were collected within 90 km of my study site to examine their age compared to decoy-trapped females. Trapping at the original study site (Walker et al. 2008) allowed me to mark and recapture mallards while potentially recapturing members of the original cohorts.

**Target Species**

I selected mallards as my target species because they (1) are the most abundant nesting duck species in the Sandhills (Vrtiska and Powell 2011), (2) decoy trap well, (3) are readily recovered by hunters, and (4) are an important duck species for waterfowl management decisions. In the spring, mallards can be found throughout the Sandhills, using wetlands to breed and acquire protein while using the grasslands for nesting. Previous research in this area also focused on the mallard (Glup and McDaniel 1987, Walker et al. 2008).
Sampling Methods

I trapped ducks with 24 spring-loaded hen-decoy traps using live, pen-raised female mallards to capture birds prior to nesting. Breeding mallard pairs will vigorously defend wetlands in their territory and will drive off other mallards that attempt to encroach on their territory (Ringelman 1990). Decoy traps take advantage of this behavior trait of territorial mallards and allow for more specific targeting of breeding pairs than rocket-netting or other trapping methods (Ringelman 1990). I placed decoy traps containing live decoy hens on wetlands where I observed mallard pairs behaving territorially the previous day (Sharp and Lokemoen 1987). Decoy traps were set in the morning at the exact location where the breeding pair was observed. Taps were checked every 24 hours, with decoy hens being replaced with a fresh bird every 3 days. I avoided returning to the trapping location during the same 24-hour period in an attempt to avoid bumping the pair off the wetland. Traps were removed from the wetland once the female had been captured or the pair had moved to another location.

I recorded the mass (± 5g) and structural size (head length, tarsus length, and keel length; ± 0.1mm) for each captured bird, and each bird was fitted with a United States Geological Survey (USGS) aluminum leg band. Female mallards were fitted with a bright yellow nasal disk to avoid targeting those birds in future trapping and to help determine if birds were remaining on the study site after capture.

I aged all captured birds based on feather characteristics and wear on the greater secondary coverts of the wing according to Carney (1992). NGPC biologists provided training on aging ducks based on feather characteristics and I received additional training
prior to the start of the 2007 field season at the Central Flyway Wing Bee in Hartford, Kansas. Birds were aged as either second-year (SY: entering first breeding season) or after second-year (ASY: entering second or higher breeding season).

I checked all captured ducks for USGS aluminum leg bands from the current or previous (2005-2006) trapping seasons and recorded their recapture location using GPS. Those not previously marked were fitted with leg bands and released. Captured pairs were released together to minimize disruption of pair bonds. The capture, handling, and marking procedures (including the use of decoy hens) were approved by the Institutional Animal Care and Use Committee (IACUC) of the University of Nebraska (IACUC protocol #05-02-008).

During the trapping season of 2008, a random sample of female mallards were collected by NGPC biologists to compare their age to decoy-trapped females from the local-scale study location. Females were jump-shot from territorial mallard pairs from locations within 90 km of my study site in Brown, western Rock, and eastern Cherry Counties in the Nebraska Sandhills. Females were not collected from the original study site to avoid disrupting the study activities already taking place at this location. I recorded the same information (mass (± 5g), structural size (head length, tarsus length, and keel length; ± 0.1mm), and age (SY:ASY)) for collected females as I recorded for trapped birds.

I compared age ratios from these two sets to determine if females from my study location are representative of other parts of the Sandhills and to investigate potential bias caused by decoy trapping. I also submitted wings from the collected sample of female
mallards to biologists at the Central Flyway Wing Bee as a blind test of my aging abilities.

**Statistical Analysis**

I requested band recovery data for all mallards banded on my study site between 1 April 2005 and 1 April 2009 from the U.S. Bird Banding Laboratory (BBL), Laurel, Maryland. I included all reported band returns within this time frame in my analysis regardless of method of recovery. I excluded anomalous birds such as those that were injured or killed during banding operations of that banding year. I used both year recapture data and band recovery information from the BBL in my analyses.

I estimated survival, fidelity, return rate (recapture), and recovery probabilities for mallards using the Burnham Live and Dead Encounters data type in program MARK (White and Burnham 1999). My capture histories were constructed using a banding year that spanned from April 1 to the following March 31. I constructed 54 different models based on sample size, observations made in the field, and biologically appropriate combinations of the following parameters based on White and Burnham (1999) and Doeherty et al. (2002), as defined below. The 54 models I constructed included a null model \((S, p, r, F)\).

\[ p_i = \text{probability that a bird present on the study site at the time of banding in year } i \text{ is recaptured at that time (return rate).} \]

I hypothesized that \(p_i\) would vary by gender and year.
\( r_i = \) probability that a bird dies during year \( i \) does so during the hunting season and is retrieved and its band reported to the BBL (recovery rate). I hypothesized that \( r_i \) would vary by gender and year.

\( S_i = \) probability that a bird alive at the time of banding in year \( i \) is alive at the time of banding in year \( i + 1 \) (survival rate). I hypothesized that \( S_i \) would vary by gender.

\( F_i = \) probability that a bird present on the study site at the time of banding in year \( i \) is also present on the study site at the time of banding in year \( i + 1 \), given that it is alive at \( i \) + 1 (fidelity). I hypothesized that \( F_i \) would vary by gender and year.

I expected survival estimates to be high, based on within-season survival estimates of Walker et al. (2008). Similarly, Walker et al. (2008) reported low nest survival, so I expected fidelity to be low (<0.4) for both male and female mallards. I used an information-theoretic approach to select models that best showed the relationships between mallard survival, fidelity, recapture, and recovery and observed nest success. I used Akaike’s Information Criterion (AIC) scores to rank models (Burnham and Anderson 1998). I used AIC weights (\( w_i \)) to determine the confidence level of each of the models. I also used model likelihood, and the number of parameters (\( k \)) of each model to assess models. I used model averaging in program MARK to average any model that did not have time specific rates in order to report gender specific rates for survival, fidelity, recapture, and recovery. I model averaged parameter estimates using the model weight and reported unconditional standard error (SE). I used program SAS to perform Pearson’s chi-square (\( \chi^2 \)) test for statistical difference.
RESULTS

Capture Data

I documented 16 species of ducks present on the study site between 2005 and 2008 (Table 1). I captured and banded 820 unique ducks representing 6 species between 1 April and 7 June; 2005-2008 (Table 2). Of these captures, 797 were unique individual mallards (2005:266, 2006:266, 2007:87, 2008:178) (Figure 3).

The mallard was by far the most common duck captured during my study. Of the 797 mallards banded between 2005 and 2008, 100 (13%) were female and 697 (87%) were male (Figure 3). Age distribution (SY:ASY) of female mallards was 2.8:1 (SY: 73.3%, ± 15.8 95% CI) [2007: 6:1 (6,1), 2008: 2.3:1 (16,7), (χ² = 0.716, df = 1, P = 0.398) (Figure 4A)]. Age distribution of male mallards was 0.9:1 (37,43) in 2007 and 0.8:1 (67,88) in 2008 (χ² = 0.196, df = 1, P = 0.658) (Figure 4B). I obtained 15 female mallards shot near my study site during 2008. Ten of the 15 collected females were aged as young (SY) birds resulting in an age distribution (SY:ASY) of  2:1 for the females collected in 2008 (Figure 5). No females previously marked with leg bands or nasal disks were recovered during the collections. This ratio [2:1 (10,5)] is similar to the overall female age ratio observed in 2007-2008 [2.8:1 (22,8)] (χ² = 0.216, df = 1, P = 0.641).

Of the 797 unique individual mallards banded on the study site (2005-2008) I obtained BBL records from 95 (12%) band returns (direct and indirect) from 1 April 2005 through 1 April 2009. Of these band returns, 12 (13%) were female and 83 (87%) were male (Figure 6). Mallards banded on my study site during the breeding season were recovered in 15 states and 2 Canadian provinces with the majority of bands recovered in
Nebraska (Table 3). The majority of band recoveries (76%, 72/95) came from within Central Flyway states and provinces (Figure 7).

I recaptured 34 unique individual mallards (4.3%, 3 female, 31 male) of the 797 mallards banded between 2005 and 2008 (Figure 8). Females marked with nasal disks were observed throughout the study site in both 2007 and 2008, but no females marked with nasal disks in 2007 were recaptured in 2008.

Parameter Estimates

The best mark-recapture model to represent mallard survival, fidelity, return rate, and recovery probabilities was the most parsimonious model, or the null model ($S\ p\ r\ F$) (model 3, Table 4). I chose this model over models with larger AIC weights ($w_i$) and lower ΔAIC values because confidence intervals indicated no difference in survival, fidelity, return rate, or recovery rates between genders, age, or over time between the top 10 models (Table 4).

Mark-recapture analysis showed that mallards banded in my study (male and female combined) had a survival rate of 0.795 (95% CI: 0.609 - 0.906) (Table 5). The top four models all had pooled survival across genders (Table 4). Model averaged survival rates were 0.866 (SE = 0.083) (95% CI: 0.610 – 0.964) for males and 0.862 (SE = 0.101) (95% CI: 0.540 – 0.971) for females.

Recovery rate from the null model (Table 5) was 0.300 (95% CI: 0.156 - 0.497). Model averaged recovery rates were 0.308 (SE: 0.099) (95% CI: 0.152 – 0.526) for males and 0.287 (SE: 0.103) (95% CI: 0.130 – 0.520) for females.
Recapture rate from the null model (Table 5) was 0.074 (95% CI: 0.033 - 0.158). Model averaged recapture rates estimated a return rate for male mallards of 0.086 (SE: 0.038) (95% CI: 0.035 – 0.199) and 0.055 (SE: 0.036) (95% CI: 0.014 – 0.187) for females.

The top models (Table 5) estimate of fidelity rate (pooled across gender) was 0.618 (95% CI: 0.283 - 0.868). Model averaged fidelity rates estimated fidelity for males at 0.514 (SE: 0.162) (95% CI: 0.228 – 0.791) and 0.706 (SE: 0.253) (95% CI: 0.179 – 0.963) for females.

DISCUSSION

Mallard Age

Sources of Error

Throughout my study, I identified potential sources of error in the assessment of mallard age. These errors were critical to assess, as they could lead to misinterpretations of age ratios in relation to fidelity, survival, recovery rate, return rate, and nest success. Potential sources of error include trap bias, misidentification of age, and sampling bias.

SY females have been known to be more susceptible to decoy trapping then ASY females (Grand and Fondell 1994), resulting in a skewed age ratio when compared to what is actually present on the landscape. Because I used decoy-traps as my method of trapping, this is a possible explanation for the higher proportion of SY females in my sample. However, females jump-shot in the Sandhills showed similar age ratios when compared to decoy-trapped females, making it unlikely that the proportion of SY birds in my sample is a result of bias caused by decoy trapping alone. Also, a large sample of
decoy-trapped birds in Canada had a more even ratio of young birds (1071 SY: 1178 ASY; Devries et al. 2003).

Aging waterfowl based on feather characteristics can be difficult to inexperienced personnel and has the potential for human induced error. As a result, I took many steps to reduce the potential for aging error during the course of my study. I received training in aging waterfowl from experienced waterfowl biologists from the NGPC in 2005 and 2006 as well as from biologists from the Central Flyway Wing Bee in 2007. In an effort to reduce the potential for bias caused by aging by multiple investigators, I was the only individual to age birds during my study. Furthermore, I submitted wings from the collected sample of female mallards to biologists at the Central Flyway Wing Bee as a blind test of my aging abilities. The results of the blind test confirmed my abilities to correctly age mallards, which suggest no error in my results relating to identification and aging methods.

It is possible that mallards trapped on my study location may have been simply passing through the Sandhills on their way to breeding grounds further north, or may have not yet been breeding due to the early timeframe in which I trapped birds. Doeherty et al. (2002) used data from birds captured by bait traps collected later in the year (August), while my study was conducted much earlier (April-June). Females, however, formed pair bonds, behaved as territorial birds, and defended wetlands aggressively. Trapped females exhibited signs of nesting (brood patches, presence of developing eggs) and remained on the study site after capture. Targeting territorial breeding females with
decoy traps may more accurately represent breeding season characteristics when compared with birds sampled with bait traps or rocket-nets.

**Young Females**

Age ratios for female mallards from my study suggested a higher proportion of SY females when compared with nesting female mallards from North Dakota (Lokemoen et al. 1990a), the Prairie Parkland Region of Canada (Devries et al. 2003, Mack 2003), and the Great Lakes Region (Davis 2008). The higher proportion of SY females in the Sandhills could be responsible for the lower than expected nest success observed by Walker et al. (2008). Young (SY) female mallards have been shown to be less successful at nesting than older (ASY) birds (Krapu and Doty 1979, Curio 1983) and have been shown to have a higher breeding season survival because of a lower reproductive investment (Cowardin et al. 1985, Dufor and Clark 2002, Hoekman et al. 2002). The trends in survival were also supported by high breeding season survival estimates on my study site observed by Walker et al. (2008), and the relatively high annual survival estimates that I provide.

Compared to SY females, ASY birds typically arrive on the breeding grounds earlier, in better physical condition, and select nesting sites that minimize nest loss (Johnson et al. 1992). Young female mallards may be forced into less suitable habitat as ASY birds exclude them from higher quality areas (Dzubin 1969, Lindstedt et al. 1986, Lokemoen et al. 1990b). With a higher proportion of SY females observed on my study site, is the proportion of SY/ASY females an indicator of poor habitat quality?

While areas of grassland-dominated landscapes such as the Sandhills traditionally result in higher survival of duck nests (Greenwood et al. 1995, Reynolds et al. 2001, Stephens et al. 2005), it is possible that the quality or composition of nesting habitat in
the Sandhills is significantly different than habitat in areas with higher rates of nest success. Land-use practices in the Sandhills consist primarily of cattle grazing, haying, and limited row-crop agriculture (Walker et al. 2008). Fire played a historic role in maintaining the ecosystem, but due to current range practices this is no longer the case (Bleed and Flowerday 1990). Cattle grazing and fire regime changes make the Sandhills unique, when compared with other mallard breeding areas. While haying and grazing can be detrimental to waterfowl nesting by reducing the density of available nesting habitat (Kruse and Bowen 1996), extensive waterfowl nesting habitat assessments have not been conducted in the Sandhills, and warrant further investigation. Even if nesting habitat in this area is different than areas with higher rates of nest success, young female mallards may still select this site because they do not encounter competition from ASY females, and all the selective cues (wetlands, invertebrate food source, grasslands, etc.) are present on the landscape. The numerous wetlands and intact grassland of the Sandhills may be an attractive cue to SY females, although the cue appears to usually be false.

Habitat quality and connectivity is important in maintaining viable duck populations. In mid-continent duck populations, nest success is typically low where predators can efficiently search small and isolated patches of fragmented habitat (Klett et al. 1988, Clark and Nudds 1991, Greenwood et al. 1995, Dahl et al. 1999). The grassland habitat of the Sandhills is relatively intact (LaGrange 2005), but low nest success was still observed in this area by Glup and McDaniel (1987) and Walker et al. (2008).

Nest destruction by predators is the most common cause of nesting failure in the Prairie Pothole Region (PPR) (Sargeant and Raveling 1992), and females are believed to
experience higher mortality during nesting because of increased susceptibility to predators (Sargeant et al. 1984). During time spent in the Sandhills, it was evident that there was a highly active mammalian predator community present on my study site. I commonly observed coyote (*Canis latrans*), raccoon (*Procyon lotor*), and stripped-skunk (*Mephitis mephitis*) on the landscape during the day. While these mammalian predators were present on the study site and are known to be an important component of nest success (Sargeant and Raveling 1992), I did not investigate aspects of predator dynamics as a part of my study. Such studies could be critical to understanding the dynamics of waterfowl production in this region.

Depredation of waterfowl nests has been documented in the Nebraska Sandhills, but primarily focused on predation by bullsnakes (*Pituophis melanoleucus*) (Glup 1986, Glup and McDaniel 1987) and did not take into account the age of nesting females. Walker et al. (2008) detected 10 types of potential nest predators in the Sandhills using baited track plates, which were dominated by mammalian predators. Young, inexperienced female mallards have a higher propensity to abandon nests are not known to select nesting sites to minimize nest loss when compared with ASY females (Johnson et al. 1992). While speculative, it is possible that habitat quality, as a result of current land-use practices and the relative inexperience of young nesting females may make nests more susceptible to predation, despite the intact nature of the Sandhills.

Even with the diverse predator community and low nest success observed by Walker et al. (2008), breeding season survival for female mallards was high (Walker et al. 2008) and overall mallard survival from my study was higher than rates from Alberta.
and Saskatchewan (Doherty et al. 2002). In contrast, similar research on greater prairie-chickens (*Tympanuchus cupido*) on my study site showed nest success to be high (60%) (L. Anderson, University of Nebraska-Lincoln, unpublished data), while nesting female survival was low. Why is nest success so different for these two ground nesting birds when faced with the same potential predator base? Is there a possible trade-off taking place in the Sandhills between low nest success and high female survival for SY mallards?

**Fidelity to the Sandhills**

Successful females are known to exhibit a higher rate of returning to a breeding area (fidelity) than unsuccessful younger females (Lokemoen et al. 1990b). While I was unable to estimate fidelity rates between age groups, I did not observe an overall low fidelity rate for mallards banded on my study site. If fidelity is related with nest success, and nest success is presumably so low in the Sandhills (Walker et al. 2008), this begs the question: Why are birds returning to the study site?

It appears that each year, approximately 40% of ASY females are not returning to the study site to nest, resulting in 40% “open space” available to be filled by other females each year. ASY females are often able to outcompete SY females for prime nesting habitat to the north (Dzubin 1969, Lindstedt et al. 1986, Lokemoen et al. 1990b). If SY females are not encountering competition from ASY birds on Sandhills wetlands during the spring, then SY females may find the Sandhills an attractive place to nest, resulting in a breeding population dominated by young, inexperienced females. Females may breed and select nest sites, but in most years achieve low nest success, but my data
suggest that 86% survive and 70% return to the Sandhills and attempt breeding again the following year. The dynamics of movement of birds from the Sandhills to the PPR should be investigated, as movement may vary between years of poor and good conditions in the PPR. Hence, “open space” in the Sandhills may not always exist for SY birds.

If SY females have low reproductive output, but are surviving the breeding season, what purpose are the Sandhills serving? Walker et al. (2008) observed a low reproductive investment (high rate of nest abandonment), but even with a diverse predator community, females had high rates of breeding season survival. My annual survival estimate also reinforces this conclusion; therefore, a trade-off breeding strategy may allow the Sandhills population, loosely defined, of mallards to remain stable in the face of low nest success. SY females survive during the breeding season without incurring heavy losses from predators, and 60% return, with more experience, to breed. In good years, SY females may even successfully produce young given the right arrangement of ecological conditions. I believe my data provides a framework for further investigations that may provide critical information about the relationships between reproductive investment, response to predators, habitat quality, fidelity, and female age. Such evidence of demographic trade-offs is rare, and the Sandhills may provide insight that would be useful in other breeding areas.

MANAGEMENT IMPLICATIONS

Waterfowl biologists have estimated the population of breeding ducks in the Sandhills could exceed 275,000 birds (Vrtiska and Powell 2011). This population,
located just south of the PPR, is not well understood, and is currently not being included in standard continental surveys or adaptive harvest management models. My study is the first to use banding data to assess this population, and my data suggest interesting dynamics. Analysis of band returns from my study showed that mallards banded in the Sandhills during the breeding season are important to Central Flyway waterfowl hunters, especially hunters in Nebraska, Oklahoma, Kansas, and Texas (Table 5). Of the 797 mallards banded on the study site between 2005 and 2008, 95 birds (87% male) were recovered by 1 April 2009. Few mallards have been banded in Nebraska. Despite the substantial number of birds breeding in the state, relationships between the Sandhills and migration and wintering habitats in other parts of the country are not well known. Continued analysis of band returns from mallards banded in the Sandhills can help form these relationships and holds potential for management at a larger scale.

Even with a high proportion of SY females and the low observed nest success by Walker et al. (2008), managers may benefit from further investigating local factors influencing productivity given the size of the population of mallards counted in the Sandhills during the breeding season, and their importance to Central Flyway waterfowl hunters.

My results, when viewed with data from Walker et al. (2008), suggest that nesting habitat quality in the Sandhills needs further investigation. On the surface, the Sandhills; with its numerous wetlands and large expanse of intact grasslands look ideally suited to produce waterfowl. However, skewed age ratios from my study and observations made by Glup (1986) and Walker et al. (2008) may imply that nesting habitat in the region may
have become degraded over time. Mallards have been shown to prefer heavier nesting cover (Higgins 1986) and intense grazing by cattle, haying, and changes in fire regime may have altered the density and diversity of nesting cover in the Sandhills. Habitat improvement activities such as tree removal, prescribed burning, delayed haying, and specialized, rotational grazing systems instead of idling land may improve the nesting quality of the habitat. Research focusing on the condition of the habitat as it relates to waterfowl production could provide valuable insight, and if warranted, local managers may choose to incorporate these measures at existing wildlife management areas or refuges, through land acquisition, or with local landowner cooperation. Working with landowners is critical in this region because 97.4% of Nebraska’s total land area is privately owned (Henebry et al. 2006).

In addition to reducing habitat quality, altered landscape features such as planted tree lines, abandoned farmhouses, and road culverts may provide additional refuge to nest predators that was not present, historically. Nest destruction by predators has been documented in the Sandhills (Walker et al. 2008), but focused primarily on destruction by bullsnakes (Glup 1986, Glup and McDaniel 1987). The relative impact of predators such as coyote, raccoon, and stripped skunk on waterfowl nests in the Sandhills is not well documented. I suggest using nest cameras to document predator impacts on mallard nests in an effort to better understand this relationship. Glup (1986 and 1987) showed that predator control can be effective in this region. However, such results may be localized and short-lived (Glup 1986, Glup and McDaniel 1987). Information gained from the use
of nest cameras can help managers target potential sources of depredation through the use of predator exclusion or predator removal if deemed necessary.

While I find it unlikely that the low nest success observed by Glup (1986) and Walker et al. (2008), is caused by a single factor, it is possible that a combination of (1) proportionally skewed number of young, inexperienced female mallards, (2) degraded nesting habitat and (3) a diverse predator community may be accountable. It is unclear if the high number of SY females is the cause or the result of low nest success in this area, but my study suggests that managers may be able to use age ratios to gradually assess an area’s potential for productivity. Managers are just beginning to understand the systems involved in waterfowl populations in the Sandhills. For example, little is known about wetland productivity and connections to breeding condition of birds, but it is likely that information gained as a result of this study will apply to similar areas.

The Sandhills population of mallards appears to be a loosely defined population with large numbers of SY birds, apparently coming from other areas to breed, as large numbers of birds do not return to the Sandhills to breed in subsequent years. This is more evidence for the continued need for flyway-wide monitoring and management on larger scales than focusing solely on individual states. However, it is also evident that small-scale dynamics, such as those observed in the Sandhills may contribute to the complex dynamics of larger flyway-wide populations of mallards, and should not be overlooked.

ACKNOWLEDGMENTS

I gratefully acknowledge J. Walker, S. Stephens, M. Vrtiska, L. Powell, and L. Ware, all part of the original project team. Biologists N. Lyman, R Stutheit, R. Walters,
T. LaGrange, A. Bishop, and B. Rutten supported my project in the Nebraska Sandhills. Sandhills landowners provided valuable access to private lands. Funding was provided by the NGPC, the University of Nebraska-Lincoln, and the Sandhills Task Force. Ducks Unlimited, the Northern Prairie Wildlife Research Center, and the NGPC provided equipment. The University of Nebraska, Barta Brothers Ranch provided housing. Biologists at the Central Flyway Wing Bee provided additional training in aging waterfowl. C. Cowan, D. Ekberg, K. Fricke, C. Goc, J. Laux, K. Niederklein, B. Schad, and B. Schmidt were some of my many valuable field assistants. The School of Natural Resources provided computer and office space for ZJC and LAP. This research was supported by Hatch Act funds through the University of Nebraska Agricultural Research Division, Lincoln, Nebraska.

LITERATURE CITED


2008. Low reproductive success of mallards in a grassland-dominated landscape in

Table 1. Species list of ducks observed on the Nebraska Sandhills study area during spring breeding seasons 2005-2008.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallard</td>
<td><em>Anas platyrhynchos</em></td>
</tr>
<tr>
<td>Northern Pintail</td>
<td><em>Anas acuta</em></td>
</tr>
<tr>
<td>Blue-winged Teal</td>
<td><em>Anas discors</em></td>
</tr>
<tr>
<td>Green-winged Teal</td>
<td><em>Anas crecca</em></td>
</tr>
<tr>
<td>Cinnamon Teal</td>
<td><em>Anas cyanoptera</em></td>
</tr>
<tr>
<td>Northern Shoveler</td>
<td><em>Anas clypeata</em></td>
</tr>
<tr>
<td>American Wigeon</td>
<td><em>Anas americana</em></td>
</tr>
<tr>
<td>Gadwall</td>
<td><em>Anas strepera</em></td>
</tr>
<tr>
<td>Canvasback</td>
<td><em>Aythya valisineria</em></td>
</tr>
<tr>
<td>Redhead</td>
<td><em>Aythya americana</em></td>
</tr>
<tr>
<td>Lesser Scaup</td>
<td><em>Aythya affinis</em></td>
</tr>
<tr>
<td>Ring-necked Duck</td>
<td><em>Aythya collaris</em></td>
</tr>
<tr>
<td>Wood Duck</td>
<td><em>Aix sponsa</em></td>
</tr>
<tr>
<td>Bufflehead</td>
<td><em>Bucephala albeola</em></td>
</tr>
<tr>
<td>Hooded Merganser</td>
<td><em>Lophodytes cucullatus</em></td>
</tr>
<tr>
<td>Ruddy Duck</td>
<td><em>Oxyura jamaicensis</em></td>
</tr>
</tbody>
</table>
Table 2. The number of unique individual ducks banded per species on the Nebraska Sandhills study area during spring breeding seasons 2005-2008.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Number banded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallard</td>
<td>797</td>
</tr>
<tr>
<td>Blue-winged Teal</td>
<td>12</td>
</tr>
<tr>
<td>Northern Pintail</td>
<td>6</td>
</tr>
<tr>
<td>Gadwall</td>
<td>2</td>
</tr>
<tr>
<td>Northern Shoveler</td>
<td>2</td>
</tr>
<tr>
<td>Wood Duck</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 3. Distribution of band recoveries (%) from mallards banded on the local-scale study site in Rock County in the Nebraska Sandhills, 1 April 2005 through 1 April 2009 as reported to the Bird Banding Lab.

<table>
<thead>
<tr>
<th>State/Province</th>
<th>Band Recoveries (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nebraska</td>
<td>29 (30.5%)</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>17 (17.9%)</td>
</tr>
<tr>
<td>Arkansas</td>
<td>10 (10.5%)</td>
</tr>
<tr>
<td>Kansas</td>
<td>8 (8.4%)</td>
</tr>
<tr>
<td>Texas</td>
<td>8 (8.4%)</td>
</tr>
<tr>
<td>Missouri</td>
<td>4 (4.2%)</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>3 (3.2%)</td>
</tr>
<tr>
<td>Mississippi</td>
<td>3 (3.2%)</td>
</tr>
<tr>
<td>South Dakota</td>
<td>3 (3.2%)</td>
</tr>
<tr>
<td>Illinois</td>
<td>2 (2.1%)</td>
</tr>
<tr>
<td>North Dakota</td>
<td>2 (2.1%)</td>
</tr>
<tr>
<td>Colorado</td>
<td>1 (1.1%)</td>
</tr>
<tr>
<td>Tennessee</td>
<td>1 (1.1%)</td>
</tr>
<tr>
<td>Louisiana</td>
<td>1 (1.1%)</td>
</tr>
<tr>
<td>Alberta</td>
<td>1 (1.1%)</td>
</tr>
<tr>
<td>Iowa</td>
<td>1 (1.1%)</td>
</tr>
<tr>
<td>Idaho</td>
<td>1 (1.1%)</td>
</tr>
</tbody>
</table>
Table 4. Top ten models showing mallard survival, fidelity, return rate, and recovery probabilities observed in the Nebraska Sandhills during 2005-2008. Models are listed in order of support. Models with larger AIC weights ($w_i$) and lower $\Delta$AIC values have more support. Models shown have $w_i > 0.03$, and $k$ is the number of parameters in each model.

<table>
<thead>
<tr>
<th>Model</th>
<th>AICc</th>
<th>$\Delta$AIC</th>
<th>$w_i$</th>
<th>Model Likelihood</th>
<th>$k$</th>
<th>Deviance</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. p g r F</td>
<td>1149.322</td>
<td>0.00</td>
<td>0.12378</td>
<td>1.0000</td>
<td>9.0000</td>
<td>50.882</td>
</tr>
<tr>
<td>S. p r F</td>
<td>1149.580</td>
<td>0.26</td>
<td>0.10875</td>
<td>0.8786</td>
<td>7.0000</td>
<td>55.224</td>
</tr>
<tr>
<td>S. p r F g</td>
<td>1151.023</td>
<td>1.70</td>
<td>0.05287</td>
<td>0.4271</td>
<td>4.0000</td>
<td>62.754</td>
</tr>
<tr>
<td>S. p g r F g</td>
<td>1151.132</td>
<td>1.81</td>
<td>0.05006</td>
<td>0.4044</td>
<td>8.0000</td>
<td>54.736</td>
</tr>
<tr>
<td>S g p g r F g</td>
<td>1151.275</td>
<td>1.95</td>
<td>0.04660</td>
<td>0.3765</td>
<td>10.0000</td>
<td>50.786</td>
</tr>
<tr>
<td>S. p g r F g</td>
<td>1151.297</td>
<td>1.98</td>
<td>0.04610</td>
<td>0.3724</td>
<td>6.0000</td>
<td>58.974</td>
</tr>
<tr>
<td>S. p r F g</td>
<td>1151.449</td>
<td>2.13</td>
<td>0.04273</td>
<td>0.3452</td>
<td>8.0000</td>
<td>55.053</td>
</tr>
<tr>
<td>S g p r F g</td>
<td>1151.527</td>
<td>2.21</td>
<td>0.04110</td>
<td>0.3321</td>
<td>8.0000</td>
<td>55.131</td>
</tr>
<tr>
<td>S. p r F t</td>
<td>1151.794</td>
<td>2.47</td>
<td>0.03595</td>
<td>0.2904</td>
<td>9.0000</td>
<td>53.354</td>
</tr>
<tr>
<td>S. p r F g</td>
<td>1152.039</td>
<td>2.72</td>
<td>0.03181</td>
<td>0.2570</td>
<td>9.0000</td>
<td>53.599</td>
</tr>
</tbody>
</table>
Table 5. Survival, recapture, recovery, fidelity estimates and associated 95% confidence intervals for mallards banded during 2005-2008 in the Nebraska Sandhills. Parameters identified are from model 3 (Table 4).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survival</td>
<td>0.7956</td>
<td>0.0759</td>
<td>0.61</td>
<td>0.91</td>
</tr>
<tr>
<td>Return Rate</td>
<td>0.0746</td>
<td>0.0298</td>
<td>0.03</td>
<td>0.16</td>
</tr>
<tr>
<td>Recovery Rate</td>
<td>0.3001</td>
<td>0.0896</td>
<td>0.16</td>
<td>0.49</td>
</tr>
<tr>
<td>Fidelity</td>
<td>0.6180</td>
<td>0.1700</td>
<td>0.28</td>
<td>0.87</td>
</tr>
</tbody>
</table>
Figure 1. Location and land cover use of the local-scale examination of age distribution and return rates of mallards in the Nebraska Sandhills, 2007-2008 (after Walker et al., 2008).
Figure 2. Location of decoy trap sites for the local-scale examination of age distribution and return rates of mallards in the Nebraska Sandhills, 2007-2008.
Figure 3. Number of individual male and female mallards banded during 2005-2008 in the Nebraska Sandhills.
Figure 4A-B. Comparison of second-year (SY) and after second-year (ASY) female (A) and male (B) mallards captured during 2007-2008 in the Nebraska Sandhills.
Figure 5. Comparison of second-year (SY) and after second-year (ASY) female mallards collected outside the study area as a bias comparison during 2008 in the Nebraska Sandhills.
Figure 6. Comparison of band recoveries of female and male mallards from birds banded on the Sandhills study location 2005-2008.
Figure 7. Location of band recoveries from mallards banded on the local-scale study site in Rock County in the Nebraska Sandhills, 2005-2008. Figure created by Ducks Unlimited using my banding data.
Figure 8. Number of individual male and female mallards recaptured during 2005-2008 in the Nebraska Sandhills.
CHAPTER 2: Landscape effects on distribution of duck broods in the Nebraska Sandhills

Abstract:

Habitat loss and wetland drainage has the potential to cause change to the distribution of ducks and their broods in the Nebraska Sandhills. Currently, biologists do not have a base map of where waterfowl production is taking place or how landscape effects are influencing broods in the Sandhills. I conducted presence/absence road surveys on routes used by the Nebraska Game and Parks Commission to record the composition and location of duck broods across the Sandhills during August 2008.

My target species were all locally breeding duck species present in the Sandhills during the nesting season. Over 17 species of ducks were observed on the survey routes and broods of nine different duck species were recorded during 2008. The four most common duck species broods observed on the survey routes were the mallard (Anas platyrhynchos), blue-winged teal (A. discors), gadwall (A. strepera), and redhead (Aytha americana). I used logistic regression, spatial modeling, and previous known information regarding duck ecology and preferred habitat to create a thunderstorm map predicting preferred brood rearing habitat in the Nebraska Sandhills. I expected the probability of occurrence of duck broods to be highest in the western Sandhills, based on the amount of intact grasslands and lack of human development. Duck broods responded positively to areas containing woodland and cropland and negatively to areas of development.

Sampling method bias and land use associated with roads in the Sandhills could be a few causes of the higher than expected ranking of areas containing woodland and cropland habitat. My study shows the need for caution when choosing sampling methods and extrapolating results based on limited surveys over a large landscape.

Roadside brood surveys do not appear to be the best survey method for generating data for the construction of a thunderstorm map in the Nebraska Sandhills. Based on the number of breeding ducks observed in this area, it is likely that many more duck broods are present on the landscape than are being accounted for by this method. While my thunderstorm map may be influenced by a small sample size and survey method used, my study suggests that managers may be able to use thunderstorm maps as an initial tool to target land for acquisition or enhancement by private or governmental agencies, if based on information from proper surveys.

The Sandhills population of ducks consists of a variety of species, consisting of large numbers of mallards and blue-winged teal. My study is evidence for the need to choose sampling methods carefully when designing large-scale surveys, as limited sampling may not accurately represent the landscape, or population as a whole. However, it is also evidence that tools like thunderstorm maps can be created for areas that previously have no system of habitat ranking, like the Sandhills. Using more comprehensive survey methods, managers can build off of these lessons and create relatively accurate tools to predict habitat suitability for unexplored populations of ducks.
INTRODUCTION

Managers in charge of conservation planning are seeing an increasing need to manage at the ecoregion scale (Mack 1993, Hagen et al. 2005, Schneider et al. 2005). Determining factors that affect duck recruitment is important when targeting areas to manipulate or conserve habitat on a landscape scale (Johnson et al. 1992, Cowardin et al. 1995). Brood surveys are traditionally used as an indication of recruitment from aerial breeding surveys (U. S. Fish and Wildlife Service [USFWS] and Canadian Wildlife Service [CWS] 1987), and may be a useful tool that managers can use to understand the spatial distribution of duck recruitment in an area. While brood surveys have traditionally been conducted in the Nebraska Sandhills; currently, there is no method of formal habitat assessment over large areas in Nebraska. Managing at the ecoregion scale requires this type of information.

One such ecoregion is the Nebraska Sandhills (Schneider et al. 2005). I studied duck brood distribution in the Nebraska Sandhills during August 2008. The Sandhills comprise the largest continuous expanse of native grassland remaining in North America, an area of approximately 5,179,976 hectares interspersed with more than 404,685 ha of wetlands (LaGrange 2005). The combination of grasslands and abundant wetlands in the Sandhills provides nesting habitat for ducks; particularly mallards, blue-winged teal (A. discors), and gadwall (A. strepera). Current population trends of breeding ducks in the Sandhills appear stable, and biologists estimate that this population could exceed 275,000
in some years (Vrtiska and Powell 2011). Thus, biologists have reason to approach waterfowl management in the Sandhills from a regional perspective.

Large tracts of intact grassland such as the Sandhills are often associated with high duck nest success, because these areas minimize the impacts of predators on ground-nesting birds (Cowardin et al. 1985, Dufor and Clark 2002, Hoekman et al. 2002, Stephens et al. 2005). In contrast to this prediction, the Sandhills region appears to support relatively low rates of nest survival (Glup 1986, Walker et al. 2008). Thus, effective management for duck productivity in the Sandhills has remained elusive.

Waterfowl brood surveys are traditionally done by air from fixed-wing aircraft (Anderson 1956, USFWS and CWS 1987, Naugle et al. 2000) or road surveys from vehicles (Anderson 1956, Diem and Lu 1960, USFWS and CWS 1987, Naugle et al. 2000). Biologists with the Nebraska Game and Parks Commission (NGPC) have conducted ground brood surveys in the Sandhills for over 20 years by driving long transects (>100 miles; NGPC 1999). These surveys were always used anecdotally as an index, with no component to assess the habitat in the region. Current waterfowl management questions in the Sandhills (Chapter 1, Walker et al. 2008) require a more formal assessment. I conducted presence/absence road surveys on the NGPC survey routes in an attempt to observe and record the presence and distribution of duck broods, assess the effectiveness the of the current survey method, and create a thunderstorm map predicting the probability of brood occurrence across the Sandhills.
I hypothesized that waterfowl brood abundance would be greatest in the western Sandhills due to the region’s permanent wetlands, lower percentage of development, and high proportion of intact grassland found on the landscape. Although wetlands in the eastern Sandhills most likely benefit from increased rainfall, I hypothesized that fragmentation due to human disturbance and a greater percentage of cropland and woodland likely off-sets this advantage.

My goal was to investigate landscape effects of duck brood distribution in the Nebraska Sandhills. My objectives were to: (1) survey and document the location and composition of duck broods across the Sandhills, (2) develop a thunderstorm map predicting the probability of occurrence of duck broods in the Sandhills, and (3) assess and modify the current annual, repeatable waterfowl brood survey to document variability in brood production in the Nebraska Sandhills.

METHODS

Study Area

The Nebraska Sandhills can be described as a patchwork of wetlands and sand dunes now stabilized by grass (Bleed and Flowerday 1990). This rich mix of wetland types and grasslands is attractive to breeding and nesting waterfowl (Bellrose 1980). Land disturbance in this area is due primarily to settlement, grazing, roads, and to lesser extent, cropland. Most of this region consists of privately-owned ranchland used for beef production (Novacek 1989, LaGrange 2005). Despite some fragmentation due to crops, roads, and farmstead tree lines, the grasslands of the Sandhills are relatively intact (Bleed
and Flowerday 1990). Several mini-ecosystems exist in the Sandhills including savannas, ephemeral wetlands, fens, and blowouts; with dunes exceeding 100m in height (Bleed and Flowerday 1990). This unique area is host to a diverse mixture of plant and wildlife. Historically, fire played a major role in maintaining Sandhill ecosystems, but due to current range practices this is no longer the case (Bleed and Flowerday 1990).

The study area for the large-scale examination of landscape effects on duck brood distribution was located on three road survey routes in the Nebraska Sandhills (Figure 1). The survey routes were designated as O’Neill (42° 28' N, 98° 39' W), Wood Lake (42° 38' N, 100° 14' W), and Lakeside (42° 3' N, 102° 25' W), based on the nearest town located to their starting point. The study area was typical of the Sandhills as a whole in terms of its climate, land-use, plant community, and duck density. I chose these locations for the survey routes primarily because they have been used for over two decades by the NGPC (NGPC, unpublished data). The justification used by NGPC to establish the routes included; (1) the landscapes have wetland density and grassland land cover which is representative of the area, (2) the abundance of waterfowl present in the area during the brood-rearing season is representative of the Sandhills region, and (3) they are the only available road network located in areas which meet the above criteria. Habitat located long the survey routes consisted primarily of wetlands, wet meadows, pastures, sandy to choppy-sand dunes, mixed-grass prairie and, overall, represents the Sandhills as a whole. Cattle grazing and haying are the predominate land-use practices in the area.
Study Design

My study was designed to survey duck broods on wetlands at three locations across the Nebraska Sandhills. I conducted presence/absence road surveys to observe and record the presence and distribution of duck broods on wetlands \( \leq 200 \) meters of the roadway. I attempted to survey a variety of wetland types and locations on the study area in an attempt to eliminate bias and to ensure my sampling method was representing the Sandhills as a whole (Figure 1). The lengths of survey routes varied, but are considered long when compared with other road-count surveys (Anderson 1956). The lengths of the three surveys were: O’Neill, 183 km; Wood Lake, 133 km; and Lakeside, 201 km. I conducted three surveys on each route from 1 August – 31 August for a total of 9 surveys. I surveyed this time of year because the majority of broods have hatched, are of large enough size to be seen on the landscape, and have not yet migrated.

Target Species

I did not limit my surveys to a target species. All locally breeding duck species were considered, but the community of waterfowl in the region primarily consists of mallards (\( A. \) platyrhinchos), blue-winged teal (\( A. \) discors), and gadwall (\( A. \) strepera) (Vrtiska and Powell 2011). Although the focus of my mark-recapture efforts at the small-scale study site (Chapter 1) was the upland-nesting mallard, I included both dabbler and diver duck species in the brood surveys to capture the diversity of species breeding in the Sandhills. I also included cavity-nesting ducks, such as wood ducks (\( Aix \) sponsa),
which are common in the Sandhills because of isolated, mature stands of trees along roads and near farmhouses.

None of the eighteen species of ducks observed on the study location are considered to be threatened or endangered. All species use the associated wetlands for brood rearing, and all are migratory (Bellrose 1980).

**Sampling Methods**

**Brood Surveys**

The original goal of my study was to use independent, double-observer road surveys (Pagano 2007) to assess variability in abundance of duck broods in wetland habitats. However, after reviewing data from preliminary surveys during the summer of 2007, I determined that there were not enough broods present on the landscape to provide an adequate sample size to analyze double-observer data. Surveys performed in 2008 were still conducted in the double-observer fashion, but I summarized the data as presence/absence data for analyses. I conducted three surveys every other week during August 2008, for a total of nine survey routes run. All wetlands within a survey route were surveyed on the same day, but two survey routes were never run on the same day.

I conducted road surveys between 0600 h to 1230 h, weather permitting (calm days with winds <15 mph at start of survey and terminated if/when winds >20 mph). Surveys were canceled in the presence of rain or high winds due to negative impacts on duck broods (Ringelman and Flake 1980) or visual obstruction from the vehicle. The vehicle was stopped at each wetland and the available habitat was glassed with binoculars
in order to detect birds located in dense vegetation. I recorded the location of all ducks observed on water or land ≤ 200 meters of the vehicle. I recorded the number of individual ducks, species present, presence of broods, number of ducklings, as well as location of ducks on the wetland for each stop.

I developed a brood data sheet for use by the two observers (Figure 2), which was used during the reconciliation process to help visualize the location of ducks and broods observed during the stop. Observations were reconciled between the two observes prior to moving onto the next wetland. During the double-observer survey, “false” information (glassing and spending time recording “fake” ducks) was also done in an attempt to keep observers from keying on movements from the other observer.

Statistical Analysis

Presence/Absence Models

I digitized the three brood survey routes in ArcGIS by overlaying my GPS locations onto a data layer of available roads in the Sandhills. I imported my recorded locations of duck broods onto these survey routes in ArcMap. I created a 200-meter buffer around each of the three survey routes and divided each route into 10-km segments.

I estimated the presence/absence (ψ) of duck broods using logistic regression and data from my 52 route segments:

$$\psi = \frac{1}{1 + e^{-z}}$$
where \( z \) is defined, for a 2-factor model \((\beta_1 + \beta_2)\), with an intercept \( \beta_0 \), as:

\[
z = \beta_0 + \beta_1 x_1 + \beta_2 x_2
\]

The use of logistic regression assumes constant detection across the 52 survey segments. I constructed 21, 1- and 2-factor models representing hypotheses based on observations made in the field, known information on duck home range size, and combinations of Grass, Woodland, Cropland, Developed, Wetland, and Sandhills Lakes landcover indices that I selected from available Sandhill indices as provided by the Rainwater Basin Joint Venture (Grand Island, Nebraska), as defined below (Table 1). I also included a null model in my model set. I hypothesized that broods would respond positively to areas consisting of high proportions of wetlands (Kantrud and Stewart 1977), lakes, or grasslands (Cowardin et al. 1985, Dufor and Clark 2002, Hoekman et al. 2002.), and negatively to areas with high proportions of cropland (Stephens et al. 2005), woodlands, or development.

I used Akaike’s Information Criterion (AIC) scores provided by the logistic procedure in SAS (SAS Institute 2008) to rank models. I calculated AIC weights \((w_i)\) to determine the confidence in each model (Burnham and Anderson 1998). I also used model likelihood and the number of parameters \((k)\) of each model in the model selection.
process. I was prepared to use model averaging to develop parameter estimates if uncertainty existed in model selection (Burnham and Anderson 1998).

Landcover Index Layers

I used Sandhills index layers as my habitat data; the spatial data were developed by the Rainwater Basin Joint Venture (Grand Island, NE) by incorporating information from landcover data and National Wetland Inventory (NWI) data for the Sandhills region of Nebraska. The index layers are the product of a two-step process, and are available at several scales. First, the base layer of information was created from a landcover mosaic of Nebraska landcovers, which was limited to the Sandhills ecoregion with a 10-km buffer. The landcover layer started as an 8-bit raster Landsat image with a 30-m cell size. Each pixel in the image represents 30m x 30m on the ground. Pixels were classified into specific habitat types to create the landcover layer. NWI layers were used to correct wetland specific information.

Habitat-specific index layers provide information about the landscape surrounding a given pixel, or location on the ground. The habitat-specific layers were created with a circular moving window to summarize the surrounding landcover or NWI classes. The moving windows begin by focusing on a pixel in the landcover, summarizing the pixels around it, and recording that value into the output layer before moving to the next pixel. To create the radius of the moving window, the number of pixels either left, right, up or down of the center pixel is multiplied by the cell size. The moving window adds up the proportion of pixels within the circular window that belong to the habitat class defined
(e.g., grass). Then, the window shifts to the right and summarizes the surrounding area around the next pixel until every pixel has been summarized. The output pixels are divided by the total pixels within the circular window to obtain the percentages of the surround landscape classes at each scale.

I performed a GIS moving windows analysis using a combination of my brood survey data and the mean value of pixels for the 6 landcover parameters I selected in each of the 52 survey route segments, at a 4 km scale. I selected 4 km as my window radius because of the highly mobile nature of duck broods (Evans et al 1952, Berg 1956, Keith 1961, Talent et al. 1982). Thus, my analysis has a spatial reference scale of 4 km surrounding my survey routes, and my inferences regarding landscape effects on productivity account for breeding duck settling patterns and brood mobility. Each landcover layer is a combination of ≥1 specific habitat types (example: Alfalfa, Corn, Fallow, Sorghum, Soybeans, Sunflowers, Wheat, and Other Ag are types used to create the Cropland layer, Table 1).

Output

The information-theoretic approach provided models that best showed the relationships between my 6 landcover parameters, observed brood locations, and probability of occurrence. I used model-averaged estimates for each landscape factor (% Grass: GR, % Woodland: WD, % Cropland: CR, % Developed: DV, % Wetland: WT, % Sandhills Lakes: SL) to create a global model, which I implemented in ArcMap’s Raster Calculator (ESRI, Redlands, CA). The Raster Calculator used the value at the $i$th pixel in
each of the six habitat-specific index layers to produce a new layer which predicated the probability of occurrence \( (\psi_i) \) of duck broods in the Sandhills. I calculated \( \psi_i \) as:

\[
z_i = \beta_0 + \beta_{GR}(GR_i) + \beta_{WD}(WD_i) + \beta_{CR}(CR_i) + \beta_{DV}(DV_i) + \beta_{WT}(WT_i) + \beta_{SL}(SL_i)
\]

with the previously defined logistic relationship between \( \psi_i \) and \( z_i \). Last, I reclassified the output layer to 4 categories of \( \psi_i \) (\( \psi_i: 0\%-25\%, 25\%-50\%, 50\%-75\%, \text{and } 75\%-100\% \)) to produce the predictive map of brood occurrence for the Sandhills region.

RESULTS

Brood Surveys

I documented 18 species of ducks present on the survey routes during August 2008 (Table 2); all routes were run as designed. I counted 24 duck broods representing 9 species in 9 survey days between August 1 and 31 August; 2008 (Table 3). The mallard was by far the most common duck brood observed during my study. Of the 24 duck broods recorded, 9 (38%) were mallard, 6 (25%) were blue-winged teal, 2 (8%) were gadwall, and 2 (8%) were redhead, while 5 other species made up the remaining 5 (21%) broods (Figure 3).

The greatest numbers of broods were observed in the eastern Sandhills. Of the 24 duck broods I recorded, 16 (67%) were on the eastern O’Neill survey route (Figure 4), 2 (8%) were in the central Sandhills on the Wood Lake survey route (Figure 5), and 6 (25%) were on the Lakeside survey route in the western Sandhills (Figure 6).
Landscape Covariates & Models

The GIS moving windows analysis showed the mean percent cover of the landscape surrounding my 52 survey route segments to be dominated by Grass (91.9%) and Wetland (23.9%), with Woodland (0.01%) and Cropland (0.8%) comprising the smallest proportion on the landscape (Table 3).

The best model to describe the probability of occurrence of duck broods observed in the Nebraska Sandhills was Developed + Woodland (model 1, Table 4). I chose this model over models with fewer parameters (k) because of the lower ΔAIC value and higher model weight (w_i) when compared among the top 9 models (Table 4). Six out of the top 9 models included a woodland component.

Due to model uncertainty and low model weights, I used model averaged estimates for the six covariates estimated from my brood survey transects. The covariates with the largest effect differing from 0 were Woodland (36.3272) and Developed (-1.0469) (Table 3).

The thunderstorm map predicting the probability of brood occurrence in the Nebraska Sandhills predicted that the majority of broods (75-100%) would be found in areas containing a Woodland habitat component (Figure 7). These areas are found predominately in the eastern Sandhills and along the Niobrara River Valley. Areas with the lowest probability of occurrence (0-25%) are associated with areas of Development and can be seen on the landscape as features such as highway networks (Figure 7).
DISCUSSION

Survey Results

The Nebraska Sandhills are considered to be an important area for breeding ducks (Bellrose 1980), and biologists have estimated that the population of breeding ducks in the Sandhills could exceed 275,000 birds (Vrtiska and Powell 2011). This population, located just south of the Prairie Pothole Region, is not well understood, and is currently not being included in standard continental surveys or adaptive harvest management models. Biologists with the NGPC have conducted ground brood surveys in the Sandhills for over 20 years. Previously, the survey data was used as an index to annual waterfowl productivity. My study was the first to use the road-count brood surveys to model the probability of duck brood occurrence as a function of habitat variables for this population. However, the number of broods observed on the survey routes was lower than expected for an area of intact grassland (Novacek 1989) and high breeding duck population estimates such as the Sandhills (Vrtiska and Powell 2011).

Although I documented 18 different species of ducks present on the 1,551 kilometers covered during my brood surveys, I only recorded 24 total duck broods. While analogous to previous brood totals from NGPC brood surveys conducted in the Sandhills (2001:42, 2002:25, 2003:22, 2004:21, 2005:37; NGPC, unpublished data), my sample size of broods observed was low when compared to other studies (Rumble and Flake 1982, Naugle et al. 2000, Pagano and Arnold 2009), but the number and composition of species represented were consistent with those found in other important
waterfowl breeding areas such as South Dakota (Naugle et al. 2000), North Dakota (Pagano and Arnold 2009), and the Parklands of Canada (Diem and Lu 1960). Thus, I suggest that the low numbers of broods observed is not the result of a difference in species composition in the Sandhills, relative to other breeding areas.

There are several factors that may have affected the low occurrence of broods on the survey routes. First, the timing of my surveys was centered on August. I chose this time because the majority of broods (even from multiple nesting attempts) should have hatched, ducklings would be of large enough size to be seen on the landscape, birds had not yet migrated, and decoy trapping on the small-scale study area (Chapter 1) would be complete. While I timed my surveys to try and account for multiple nesting attempts, conducting brood surveys late in the year could have created bias in my survey results. Broods are known to behave differently as they age (Ringelman and Flake 1980), with older broods exhibiting lower detection probabilities when compared with young broods (Giudice 2001). With pairs observed exhibiting breeding behavior in the Sandhills as early as April 1 (Chapter 1), it is possible that ducklings from early nesting attempts were past class III stage (Gollop and Marshall 1954) by the time brood surveys were conducted, and thus, might not have been included in my sample size. In addition, birds may have made molt migrations to larger water, or early migrating species such as blue-winged teal, which made up 25% of my observed broods (Figure 3), may have migrated south by the end of August.
Second, habitat conditions late in the year may also make detecting birds difficult. The majority of broods observed on the survey routes were observed on permanent wetlands or cattle ponds, as evapotranspiration reduced the size and percent open water of many wetlands. Hammond (1970) indicated a relationship in brood visibility and detection with the percentage of open water on a given pond, and visual obstruction and percent vegetative cover are known to have a negative impact on the detection of mallard broods (Giudice 2001).

Third, I believe dense shoreline and emergent vegetation present in the Sandhills during August may have kept me from observing all broods; in fact, a very cursory analysis of my data, pooled across all habitat types, suggested detectability was less than 100% (Z. Cunningham, unpublished data). Although I attempted to allow sufficient time to scan each wetland, the time required to run such long survey routes probably increased the chances of missing a brood. The length of the NGPC survey routes also prohibited me from using local habitat variables in my analysis (e.g., within-wetland vegetation measurements), and my sample size prohibited use of double-observer methods to assess detectability by habitat covariates.

Despite lower than expected brood numbers, I believe my data accurately represents the quantity of broods on the landscape. Recent information suggests that nest success (Walker et al. 2008) and breeding population estimates (Vrtiska and Powell 2011) in the Sandhills may be lower than previously thought. In fact, cursory calculations using the percent nest success found by Walker et al. (2008; 3%), breeding
population estimates from Vrtiska and Powell (2011; 275,000 ducks), and the percentage of the Sandhills surveyed during my brood surveys (0.6%) support the low number of broods observed during my study. As an approximation, 275,000 ducks would represent 137,500 pairs, which could be expected to each produce two nests (275,000 nests), of which 3% would produce broods resulting in 8,250 broods in the Sandhills. I would have expected to observe 0.6% of the broods (50 broods) on my survey routes, if the broods were distributed randomly throughout the Sandhills. If pairs only produced one nest per year, this estimate would be cut in half to 25 broods seen on my surveys; I observed 24 broods. The high proportion of inexperienced, SY female mallards recently observed in the Sandhills (Chapter 1) may be a contributing factor to the low densities of broods observed in this area, and warrants further investigation.

**Thunderstorm Map**

Despite the fact that areas of grassland-dominated landscapes, such as the Sandhills, traditionally result in higher survival of duck nests (Greenwood et al. 1995, Reynolds et al. 2001, Stephens at al. 2005), the best model to describe the variability in occurrence of duck broods observed in the Nebraska Sandhills included factors of Developed (negative effect) and Woodland (positive effect) habitat (model 1, Table 4). In fact, six out of my top 9 models included a woodland component. The O’Neill route (Figure 4) was the survey route with the greatest amount of trees on the landscape, and it also had the most broods observed. Trees may be an indicator of higher levels of precipitation, which could provide areas of dense grass for better protection from nest...
predators. It is possible that another, unmeasured, factor was responsible for this route having the most broods. While an important factor in my models, *Woodland* only made up 0.01% of the mean percent cover of the landscape surrounding my 52 survey route segments. Conversely, *Grass* made up 91.9% of the mean percent cover surrounding my survey routes, but was found in only 1 of the top 9 models.

The high score of the *Woodland* covariate may also be an artifact of the survey design. There are few roads through the Sandhills when compared to the grid system found throughout majority of Nebraska. Windbreaks, homestead plantings, shade trees and other woodland components that are found along the current road system were not historically part of the Sandhills ecoregion until settlement of the Sandhills occurred (Bleed and Flowerday 1990). While the 3 survey routes covered a variety of habitats, road-count surveys will always be influenced by the limited road access in the Sandhills.

The large covariate value estimated for *Woodland* habitat influenced the thunderstorm map, as the predictive map of brood occurrence in the Nebraska Sandhills suggested a high relative probability for finding broods (75-100%) in areas containing a *Woodland* habitat component (Figure 7). These areas are found predominately in the eastern Sandhills and along the Niobrara River Valley; high waterfowl productivity was not predicted in large expanses of grassland, which deviated from my expectations. Areas on the map with the lowest probability of occurrence (0-25%) are associated with areas of *Development* (Figure 7). Ironically, roads, to which the current survey method is inherently tied, are one of the habitat types used to form the *Development* index.
Although I was able to produce a functional thunderstorm map using brood data, inferences made from the thunderstorm map should be limited at this time because of the survey method used. My current conclusion is to regard the spatial predictions of productivity with caution, because of the small sample sizes that were used to develop landscape relationships. However, the process of creating the predictive map had value, and the methods that I established can be used with data from future surveys to better predict productivity of waterfowl in the Sandhills. Such information remains an important tool for management decisions in the Central Flyway.

**MANAGEMENT IMPLICATIONS**

The Sandhills population of ducks consists of a variety of species, consisting of large numbers of mallards and blue-winged teal. On the surface, the Sandhills; with its numerous wetlands and large expanse of intact grasslands look ideally suited for brood production. However, low brood numbers from my study and observations made by Glup (1986) and Walker et al. (2008) may imply that productivity in the region is lower than previously thought.

Analysis of my brood survey routes produced the first thunderstorm map predicating the probability of occurrence of duck broods in the Nebraska Sandhills. However, traditional road-count brood surveys do not appear to be an effective method to assess this population. To produce management tools such as thunderstorm maps, there is a need for survey methods with high levels of detectability and the ability to cover large sections of the landscape. In addition, occurrence estimates require good sample
sizes within different habitat types. Modified brood surveys or traditional fixed or rotary-wing aerial surveys may more appropriately fit this need.

The current brood surveys do not adequately cover the Sandhills or provide a large enough sample size produce an accurate thunderstorm map, and thus need improvement. If road-count brood surveys are going to be used in this fashion, I recommend breaking these transects into smaller segments located throughout the Sandhills, and conducting future surveys as a staggered sequence from June-August to better assess the timing of broods in this area. Using more comprehensive survey methods such as walk-up brood surveys or brood beat-outs to allow for a more in-depth examination of local habitat conditions would improve the relationship between local-scale habitat covariates and brood occurrence.

Despite the substantial number of ducks breeding in the state, relationships between habitat and brood production and is not well known in the Sandhills. Continued improvement and implementation of brood surveys can help form these relationships and holds potential for management at the ecoregion scale.

Even with low numbers of observed broods, a high proportion of breeding SY females (Chapter 1), and the low observed nest success by Walker et al. (2008), managers may benefit from further investigating local factors influencing productivity given the size of the population of mallards counted in the Sandhills during the breeding season. Using a more comprehensive sampling method, managers may be able to produce thunderstorm maps that more accurately predict where broods are most likely produced
on the landscape. These maps could be a tool used to target land for habitat improvement projects or acquisition by private or governmental agencies.

My study is evidence for the need to choose sampling methods carefully when designing large-scale surveys, as limited sampling may not accurately represent the landscape, or population as a whole. However, it is also evidence that tools like thunderstorm maps can be created for areas that previously have no system of habitat ranking, like the Sandhills. Using more comprehensive survey methods, managers can build off of these lessons and create relatively accurate tools to predict habitat suitability for unexplored populations of ducks.

Managers are just beginning to understand the systems involved in waterfowl populations in the Sandhills, but it is likely that information gained as a result of this study will apply to similar areas. This is more evidence for the continued need for flyway-wide monitoring and management on the ecoregion scale, as well as the value for an assessment of how monitoring data are to be used. Although many large-scale monitoring surveys were developed for use as annual indices, there is now a need for addressing ecological relationships with the data. Efforts that provide habitat-specific predictions of productivity require larger samples than annual productivity indices. My assessment suggests that biologists must address the tradeoffs of costs for more intensive surveys, relative to the value of the information provided.
ACKNOWLEDGMENTS

I gratefully acknowledge M. Vrtiska, L. Powell, and A. Bishop, all part of the project team. Biologists N. Lyman, R. Walters, S. Stephens, and J. Walker, provided expertise and technical assistance. Funding was provided by the NGPC and the University of Nebraska-Lincoln. The NGPC provided equipment. T. Nieveen was the second observer during brood survey data collection. K. Fricke conducted preliminary brood surveys in 2007. The School of Natural Resources provided computer and office space for ZJC and LAP. This research was supported by Hatch Act funds through the University of Nebraska Agricultural Research Division, Lincoln, Nebraska.

LITERATURE CITED


Keith, L. B. 1961. A study of waterfowl ecology on small impoundments in


Table 1. The six landcover indices and associated habitats selected from the Sandhill landcover layer as provided by the Rainwater Basin Joint Venture. Each landcover index includes ≥1 specific habitat types, and some habitat types appear in >1 index.

<table>
<thead>
<tr>
<th>Landcover indices</th>
<th>Habitat types used to form index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass</td>
<td>CRP grass, CRP, Mixed Grass, Sandhills Grasslands, Shortgrass, Tallgrass, Wet Meadow</td>
</tr>
<tr>
<td>Woodland</td>
<td>CRP upland trees, CRP riparian trees, Eastern Red Cedar, Ponderosa pine-many trees/little grassy understory, Upland Woodland, Ponderosa Pine, Juniper, Ponderosa Pine-few trees/grassy understory, Riparian Canopy, Exotic Riparian Shrubland, Native Riparian Shrubland</td>
</tr>
<tr>
<td>Cropland</td>
<td>Alfalfa, Corn, Fallow, Sorghum, Soybeans, Sunflowers, Wheat, Other Ag</td>
</tr>
<tr>
<td>Developed</td>
<td>Other Roads, Rural Developed, 4-Lane Roads, Urban/Suburban</td>
</tr>
<tr>
<td>Wetland</td>
<td>Playas, Sandhills Wetlands, CRP wetlands, Canals, Freshwater Lake/Sandhill Lake, Sand Pit/Irrigation reuse pit, Reservoir, Stock Pond, Emergent Marsh, Saline Marsh, River Channel, Wet Meadow, Floodplain Marsh</td>
</tr>
<tr>
<td>Sandhills Lakes</td>
<td>Sandhills Lakes</td>
</tr>
</tbody>
</table>
Table 2. Species list of ducks observed on the Nebraska Sandhills survey routes, 2008.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallard</td>
<td><em>Anas platyrhynchos</em></td>
</tr>
<tr>
<td>Northern Pintail</td>
<td><em>Anas acuta</em></td>
</tr>
<tr>
<td>Blue-winged Teal</td>
<td><em>Anas discors</em></td>
</tr>
<tr>
<td>Green-winged Teal</td>
<td><em>Anas crecca</em></td>
</tr>
<tr>
<td>Cinnamon Teal</td>
<td><em>Anas cyanoptera</em></td>
</tr>
<tr>
<td>Northern Shoveler</td>
<td><em>Anas clypeata</em></td>
</tr>
<tr>
<td>American Wigeon</td>
<td><em>Anas americana</em></td>
</tr>
<tr>
<td>Wood Duck</td>
<td><em>Aix sponsa</em></td>
</tr>
<tr>
<td>Gadwall</td>
<td><em>Anas strepera</em></td>
</tr>
<tr>
<td>Canvasback</td>
<td><em>Aythya valisineria</em></td>
</tr>
<tr>
<td>Redhead</td>
<td><em>Aythya americana</em></td>
</tr>
<tr>
<td>Lesser Scaup</td>
<td><em>Aythya affinis</em></td>
</tr>
<tr>
<td>Ring-necked Duck</td>
<td><em>Aythya collaris</em></td>
</tr>
<tr>
<td>Bufflehead</td>
<td><em>Bucephala albeola</em></td>
</tr>
<tr>
<td>Ruddy Duck</td>
<td><em>Oxyura jamaicensis</em></td>
</tr>
<tr>
<td>Hooded Merganser</td>
<td><em>Lophodytes cucullatus</em></td>
</tr>
<tr>
<td>Goldeneye</td>
<td><em>Bucephala clangula</em></td>
</tr>
<tr>
<td>Common Merganser</td>
<td><em>Mergus merganser</em></td>
</tr>
</tbody>
</table>
Table 3. Mean, standard deviation, and model averaged estimates for the six covariates estimated from brood survey transects conducted in the Nebraska Sandhills during August 2008. Mean and standard deviation represent the percent cover of 52 segments along the 517 km transects.

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Segment Mean&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Segment SD</th>
<th>Model Averaged Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed</td>
<td>1.096</td>
<td>0.810</td>
<td>-1.0469</td>
</tr>
<tr>
<td>Woodland</td>
<td>0.013</td>
<td>0.065</td>
<td>36.3272</td>
</tr>
<tr>
<td>Cropland</td>
<td>0.805</td>
<td>2.497</td>
<td>0.0707</td>
</tr>
<tr>
<td>Wetland</td>
<td>23.857</td>
<td>19.339</td>
<td>0.0013</td>
</tr>
<tr>
<td>Sandhills Lakes</td>
<td>1.528</td>
<td>2.342</td>
<td>-0.0054</td>
</tr>
<tr>
<td>Grass</td>
<td>91.873</td>
<td>3.975</td>
<td>0.0006</td>
</tr>
<tr>
<td>Intercept</td>
<td>—</td>
<td>—</td>
<td>-0.4649</td>
</tr>
</tbody>
</table>

<sup>a</sup> As indices do not add up to 100%
Table 4. Top nine models describing probability of occurrence of duck broods observed in the Nebraska Sandhills during August 2008. Models are listed in order of support. Models with larger AIC weights ($w_i$) and lower $\Delta$AIC values have more support. Models shown have $w_i > 0.01$, and $k$ is the number of parameters in each model. Thirteen models with $w_i < 0.01$ are not shown; null model $w_i = 0.008$.

<table>
<thead>
<tr>
<th>Model name</th>
<th>AICc</th>
<th>$\Delta$AIC</th>
<th>$w_i$</th>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Developed + Woodland</td>
<td>49.800</td>
<td>0.000</td>
<td>0.510</td>
<td>3</td>
</tr>
<tr>
<td>2  Developed + Cropland</td>
<td>52.110</td>
<td>2.310</td>
<td>0.161</td>
<td>3</td>
</tr>
<tr>
<td>3  Woodland</td>
<td>54.040</td>
<td>4.240</td>
<td>0.061</td>
<td>2</td>
</tr>
<tr>
<td>4  Wetland + Woodland</td>
<td>55.013</td>
<td>5.213</td>
<td>0.038</td>
<td>3</td>
</tr>
<tr>
<td>5  Woodland + Sandhills Lakes</td>
<td>55.238</td>
<td>5.438</td>
<td>0.034</td>
<td>3</td>
</tr>
<tr>
<td>6  Grass + Woodland</td>
<td>55.980</td>
<td>6.180</td>
<td>0.023</td>
<td>3</td>
</tr>
<tr>
<td>7  Cropland + Woodland</td>
<td>56.006</td>
<td>6.206</td>
<td>0.023</td>
<td>3</td>
</tr>
<tr>
<td>8  Cropland</td>
<td>56.112</td>
<td>6.312</td>
<td>0.022</td>
<td>2</td>
</tr>
<tr>
<td>9  Developed + Wetland</td>
<td>56.342</td>
<td>6.542</td>
<td>0.019</td>
<td>3</td>
</tr>
</tbody>
</table>
Figure 1. Location of brood survey routes in the Nebraska Sandhills, 2008.
Figure 2. Survey route datasheet created for duck brood surveys conducted in the Nebraska Sandhills, August 2008. Pond number 1 is an example showing the observation of 3 ducks and no broods, with X’s representing duck locations on the wetland.
Figure 3. Composition of ducks species broods observed during brood surveys in the Nebraska Sandhills, 2008.
Figure 4. Location of positive brood observations on the O’Neill survey route in the Nebraska Sandhills, 2008.

Some brood locations represent multiple brood observations.
Figure 5. Location of positive brood observations on the Wood Lake survey route in the Nebraska Sandhills, 2008.

Some brood locations represent multiple brood observations.
Figure 6. Location of positive brood observations on the Lakeside survey route in the Nebraska Sandhills, 2008. Some brood locations represent multiple brood observations.
Figure 7. Thunderstorm map predicting probability of occurrence of duck broods in the Nebraska Sandhills, based on brood surveys competed in August 2008. Spatial model was constructed using the six landscape indices and model averaged coefficients in Table 3.