

12-13-2014

Survival and Habitat Selection of American Black Ducks in Tennessee

Kira Cristina Newcomb

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Survival and habitat selection of American black ducks in Tennessee

By

Kira Cristina Newcomb

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Wildlife and Fisheries Science
in the Department of Wildlife, Fisheries, & Aquaculture

Mississippi State, Mississippi

December 2014

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Kira Cristina Newcomb

2014

Survival and habitat selection of American black ducks in Tennessee

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American black duck (*Anas rubripes*) populations declined throughout North America from 1950–1990, but the breeding population since has stabilized. However, limited information exists on black ducks in the Mississippi Flyway, where wintering populations continue to decline. I radiomarked 111 female black ducks at Tennessee National Wildlife Refuge (TNWR) in winters 2010–2012 to estimate winter survival and investigate patterns of habitat selection. Winter survival (83–85%) was greater than or comparable to previous estimates for black duck populations in North America. Interval survival increased 0.6% with a 100 g increase in body mass, but survival differed between years and waterfowl hunting seasons relative to body mass. Black ducks selected habitats on TNWR and emergent/scrub-shrub wetlands throughout winter regardless of hunting season or time of day. High winter survival rates and consistent use of TNWR suggest the refuge provides an important complex of habitats for black ducks wintering in Tennessee.

DEDICATION

The road to truth is always under construction; the going is the goal.

– Morris Berman

I could not have walked this road without you by my side.

ACKNOWLEDGEMENTS

This project was funded by Central Hardwoods Joint Venture, Forest and Wildlife Research Center and Mississippi State University, University of Tennessee Institute of Agriculture, and U.S. Fish and Wildlife Service (USFWS). I appreciated the knowledge and support of all faculty, staff, and students in the Department of Wildlife, Fisheries, and Aquaculture. The USFWS personnel and interns at Tennessee National Wildlife Refuge were incredibly supportive during all phases of this project, especially Clayton Ferrell who I thank endlessly for everything he has shared with me in the past 4 years. Thank you to Ducks Unlimited and Cyprus Knee Chufa for making donations that facilitated this project. Tennessee Wildlife Resources Agency allowed access to state land, and Swor Aviation provided transportation for aerial telemetry. Dave Fronczak with USFWS and Kyle Brehe with the Southern Regional Climate Center provided waterfowl survey and weather data, respectively.

There are many people who deserve my gratitude and recognition for their contributions to the successful completion of this project. I would like to thank my major advisor, Dr. Brian Davis, and committee members, Drs. Rick Kaminski and Matt Gray, for their support and assistance on this project. Field work would have been much less productive and enjoyable without the knowledge, patience, enthusiasm, creativity, humor, flexibility, and hard work of field crew members. To Cam, Alex, Randy, Tom, Scott, and Susan — I would not have learned as much or survived field work without you.

Additionally, Dr. James Martin was a wealth of knowledge and support, and I am very grateful to have been an adopted member of the Ag Ecology Lab. Thanks to Dr. David Evans in the Department of Forestry at Mississippi State, who spent hours teaching and coaching me through supervised classification. Dr. Josh Stafford, Aaron Yetter, and the crew at Illinois Natural History Survey taught me how to attach transmitters and answered a plethora of questions. I appreciated the expertise of Dr. Pat Donohoe, Dr. Bruce Davis, and many others for their help debunking the Chevy's telemetry system. Dr. Kevin Ringelman at Louisiana State University engaged in valuable discussions on habitat selection analyses, and Dr. Mike Schummer at State University of New York – Oswego provided guidance on use of the Weather Severity Index. Ted Barney at Long Point Waterfowl and many hunters provided valuable information on harvested black ducks. I would also like to extend my gratitude to Drs. Jessica Tegt and Leslie Burger for being professional inspirations and encouraging me to be a part of youth education and outreach.

Finally, to my family and friends in Mississippi and elsewhere — your love, encouragement, and sometimes harassing were essential in this endeavor, as in all of mine. Adrian, you are my rock. Thank you all for being the ears that listened and the ones I could rely on for a bit of fun! Thanks also to all the members of Mississippi State's Team Duck, especially Joe Lancaster and Justyn Foth, who supported me and opened my eyes to the world of waterfowl. I still have not harvested a duck, but I have greatly enjoyed watching, eating, and hearing stories about them!

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CHAPTER I
SURVIVAL OF FEMALE AMERICAN BLACK DUCKS WINTERING IN WESTERN
TENNESSEE

Introduction

The historic range of the American black duck (*Anas rubripes*; hereafter black duck) once extended over the eastern third of the United States (Figure 1.1; Longcore et al. 2000*b*). The first annual Mid-winter Waterfowl Survey (MWS) was conducted in 1955, and an estimated 750,000 black ducks were counted in eastern North America, with 75% and 25% occurring in the Atlantic and Mississippi Flyways, respectively (Black Duck Joint Venture [BDJV] 2008). However, black ducks declined throughout their range between the 1950s and 1990s, and the MWS abundance index for black ducks was still only 288,800 in 2014 (Rusch et al. 1989, Conroy et al. 2002*a*, United States Fish and Wildlife Service and Canadian Wildlife Service [USFWSCWS] 2004, Devers and Collins 2011, USFWS 2014*a*).

The MWS traditionally has been used to count wintering waterfowl and monitor populations (Link et al. 2006, United States Fish and Wildlife Service [USFWS] 2014*a*). However, the MWS has inherent problems, such as observer-related and other inconsistencies among states in survey methodology, which bias population indices (Eggeman and Johnson 1989, Rusch et al. 1989, Conroy et al. 2002*a*, Link et al. 2006, Brook et al. 2009, Soulliere et al. 2013). To circumvent possible bias associated with the

MWS indices and produce a statistically defensible population estimate, the traditional Breeding Waterfowl and Habitat Survey was expanded in 1990 to include aerial transect surveys for breeding waterfowl populations (BPOP) in core black duck breeding areas (i.e., eastern survey area; Zimmerman et al. 2012, Zimpfer et al. 2014). Thus, analyses of black duck population trends are increasingly robust by incorporating BPOP data (Zimmerman et al. 2012, Zimpfer et al. 2014). Since 2005, hierarchical models incorporating BPOP data from USFWS and CWS aerial surveys have been used to estimate population sizes of breeding black ducks in eastern North America (CWS Waterfowl Committee [CWSWC] 2008, USFWS 2014a). Combined USFWS and CWS breeding data estimated 618,700 (90% CI: 552,100, 699,100) black ducks in the eastern survey area in 2014, which is similar to the 1990–2013 average (USFWS 2014a, Zimpfer et al. 2014). Additionally, the total black duck population was estimated to be 901,700 in 2011 (95% CI: 715,200, 1,274,000; Zimmerman et al. 2012).

Both breeding and winter survey data reveal contrasting population trends of black ducks throughout the species' range. Declines are occurring in southern, western, and central sectors of the range, whereas stabilization or slight increases are occurring in northeastern sectors (USDICWS 1998, Link et al. 2006, Brook et al. 2009, Zimmerman et al. 2012). Despite stabilization of some regional black duck populations, declines continue in the Mississippi Flyway. There has been a two-fold decrease in MWS abundance index for black ducks in the Atlantic Flyway between 1955 and 2014 (582,453 to 269,000), while the index for the Mississippi Flyway shows a 9-fold decrease during this same period (178,400 to 19,700; Fronczak 2012, USFWS 2014a).

Factors potentially causing declines in black duck populations have been debated for decades (Rusch et al. 1989, Conroy et al. 2002a). Harvest and hunting-related disturbance, competition and introgressive hybridization with mallards (*A. platyrhynchos*), and loss and degradation of wintering and breeding habitat are among the most implicated (Rusch et al. 1989, Nudds et al. 1996, Conroy et al. 2002a). Despite conservative harvest restrictions imposed in 1983 following a lawsuit against USFWS, uncertainty exists as to whether harvest restrictions have benefitted black duck populations (Feierabend 1984, Francis et al. 1998, Zimpfer 2006). Both additive and compensatory hunting mortality have been demonstrated to some extent, and some populations and sex/age groups of black ducks exhibit differential risk to hunting pressure (Krementz et al. 1987, Krementz et al. 1988, Longcore et al. 2000a). Krementz et al. (1988) found no evidence to support compensatory mortality for black ducks in the Mississippi Flyway, and results from their analysis of Tennessee River female black ducks indicated that hunting was additive for this population. An adaptive harvest management (AHM) framework has been established and first was implemented for the 2013 hunting season (USFWS 2014b). The AHM framework for black ducks considers 2 hypotheses for factors limiting population growth: 1) additive hunting mortality and 2) competition with mallards during the breeding season (USFWS 2014b).

Black duck declines have been attributed to competition and introgressive hybridization with mallards (Johnsgard and DiSilvestro 1976; Ankney et al. 1987, 1989; Petrie et al. 2012). Extensive deforestation, conversion to agriculture, game farm releases, and likely other factors exacerbated the expansion of the mallard range eastward in North America (Johnsgard 1967, Heusmann 1974, Johnsgard and DiSilvestro 1976).

Mallards, where once relatively less abundant, currently thrive in much of the black duck's range (Heusmann 1974). Thus, this increased co-existence has led to concerns over acquisition of suitable habitat and mates by black ducks (Brodsky and Weatherhead 1984, Brodsky et al. 1988, Merendino et al. 1993, Maisonneuve et al. 2006). Research on competitive exclusion and introgressive hybridization between the species continues to fuel on-going debate (Conroy et al. 1989*b*, Dwyer and Baldassarre 1993, Morton 1998, Mank et al. 2004, McAuley et al. 2004, Petrie et al. 2012). Despite nearly 50 years of research, there has been no clear consensus on the cause of declining black duck populations, especially regarding the degree of impact mallards have on these populations.

Researchers have hypothesized that degraded habitat conditions negatively impact waterfowl populations (Gilmer et al. 1982, Prince et al. 1992, Bethke and Nudds 1995, Losito and Baldassarre 1995, Green 1996). Declines in quantity and quality of habitats used during breeding and wintering periods, which include forested wetlands, mudflats, coastal salt marshes, and palustrine emergent wetlands, may be negatively affecting black duck populations (Rusch et al. 1989, Conroy et al. 2002*a*). In addition, intensification of agriculture (Maisonneuve et al. 2006), low densities and availability of food resources (Steckel 2003, Plattner et al. 2010, Cramer et al. 2012), erosion of coastal areas (Erwin et al. 2011), environmental contaminants (Silver and Nudds 1995), and human disturbance (Morton et al. 1989*a*, Morton 1998) may all have detrimental effects on black duck populations.

A recent hypothesis proposed that greater declines of black ducks in southwestern areas of their range than in other sectors also may be related to a shift in their range rather

than an actual decrease in populations (Brook et al. 2009). Greater declines of black ducks in the Mississippi Flyway and western portions of BPOP and MWS areas may reflect shifting distributions of these birds to the north and east (USDICWS 1998, Brook et al. 2009, Devers and Collins 2011). Link et al. (2006) used Christmas Bird Count (CBC) data from 1966–2003 to corroborate regional declines observed in MWS data. Analyses confirmed species declines in central and western bird conservation regions (e.g., Central Hardwoods and Mississippi Alluvial Valley), whereas there was apparent stability in northeastern regions (e.g., Lower Great Lakes and Atlantic Northern Forest; Link et al. 2006). Moreover, Brook et al. (2009) reported that as black ducks decreased in the MWS, they increased in mid-winter counts (1986–2005) from the Canadian shores of Lake Ontario and the St. Lawrence River. Thus, these recent analyses support the possibility of a northeastern winter range shift or changes in migration phenology of black ducks, which may partly explain observed declines in the MWS (Link et al. 2006, Brook et al. 2009).

Research into factors possibly exacerbating declines in black duck populations is especially important in the Mississippi Flyway, where the steepest declines have occurred. From 1955–1999, approximately 30% of black ducks counted during the MWS occurred in the Mississippi Flyway, whereas only 10% of black ducks counted during the MWS in the last decade occurred there (Fronczak 2012). Within the Mississippi Flyway, Tennessee wintered the most black ducks in 33 (56%) of the last 59 years, averaging approximately 33,851 from 1955–1999; this number dropped to an average of about 8,108 black ducks from 2000–2013 (Fronczak 2012, USFWS 2014a). Tennessee and Cross Creeks National Wildlife Refuges (NWRs) historically wintered the most black

ducks in Tennessee (Sanders 1995), with Tennessee NWR (TNWR) holding >50% of black ducks in the state, or about 22% of black ducks in the Mississippi Flyway (Fronczak 2012; R. Wheat, USFWS, unpublished data). However, black ducks wintering on TNWR have declined precipitously, from approximately 20,000 black ducks in 1964 to 1,404 in 2013 (R. Wheat, USFWS, unpublished data).

The nonbreeding period for most waterfowl extends nearly 8 months, and significant biological and social events occur during this time (Hepp 1986, Conroy et al. 1989a, Weller 1988, Robertson and Cooke 1999, Baldassarre and Bolen 2006). Accessible, quality food and disturbance-free areas are essential resources for wintering waterfowl (Reinecke et al. 1982, Whyte and Bolen 1984, Robb et al. 2001, Dooley et al. 2010b, Legagneux et al. 2009). Survival of waterfowl in winter can be greatly impacted by age, body condition, hunting-related effects (e.g., disturbance, direct mortality), and availability of sanctuary (Krementz et al. 1988, Conroy et al. 1989a, Longcore et al. 2000a, Dooley et al. 2010a, Davis et al. 2011). Reinecke et al. (1982) suggested that winter is the most stressful period in the annual cycle for black ducks.

Despite intensive research on black ducks in North America, surprisingly limited information exists on winter survival of black ducks in the Mississippi Flyway. Chipley (1995) radiomarked female black ducks at TNWR in winters 1990–1992 and estimated survival rates of 0.94 in 1991–1992 and 1.0 in 1990–1991 (Chipley 1995). Chipley (1995) could not find linkage between black duck survival and body condition, age, or levels of lead in the ducks' blood. Chipley (1995) attributed high survival rates of black ducks to a mild winter, generally above average precipitation, no hunting pressure, and a small sample size of radiomarked females ($n = 68$ for both winters). Robb (1997) studied

radiomarked black ducks from October–January 1990–1993 on Ottawa NWR in Ohio. He estimated survival rates of female juvenile black ducks for nonhunting risk (0.77) by censoring hunting-related mortalities and for overall risk (0.56) by including all mortalities in survival analyses (Robb 1997). Moreover, Robb (1997) found that black duck survival was influenced by the number of hunting days per week, but average weekly temperatures and body condition were not related to survival. Despite not finding a statistical effect of body condition on survival, Robb (1997) observed negative effects of radio transmitters on birds' condition (e.g., recaptured radiomarked birds had greater weight loss than recaptured banded birds), which may have exacerbated losses of black ducks to predators, especially those birds released during bouts of severe winter weather.

Given concerns over declining black duck populations in the Mississippi Flyway and specifically at TNWR, my objectives were to provide contemporary survival estimates of black ducks at an important wintering area in the Mississippi Flyway and to determine biotic and abiotic factors that may impact black duck survival at TNWR. Current winter survival estimates and identification of factors affecting survival will provide valuable information for population and habitat management for this species at a major wintering site and elsewhere in the birds' winter range in the Mississippi Flyway.

Study area

My primary study area was the Duck River Unit (DRU; 35°57'30 N, 87°57'00 W) of TNWR in western Tennessee (Figure 1.2). The DRU is the largest (10,820 ha) of 3 wetland complexes comprising TNWR (20,784 ha). Primary resources on the DRU include: 1) seasonally-flooded, emergent herbaceous (i.e., moist-soil) wetlands (594 ha), 2) cooperatively-farmed row crop agriculture (673 ha), 3) impounded open water (537

ha), 4) woody sloughs, scrub-shrub, and bottomland hardwoods (2,016 ha), 5) uplands dominated by oak-hickory (2,468 ha), and 6) portions of Kentucky Reservoir (3,458 ha) and the Duck River (777 ha). Agricultural crops grown at TNWR include corn, millet, grain sorghum, winter wheat, soybeans, and clover. Interior levees divide the DRU into 14 managed impoundments, and an outer perimeter levee helps protect impoundments from flooding by Kentucky Reservoir and the Duck River. Waterfowl hunting is not permitted on TNWR, but hunting occurs on surrounding private and public lands. Most roads within DRU are closed to foot and vehicular traffic from 15 November–15 March each year, which further limits disturbance to waterfowl.

Methods

Trapping and transmitter attachment

I trapped black ducks at DRU from November through early February 2010–2012. I deployed swim-in traps where I consistently observed black ducks from ground vantage sites. I constructed these traps of 1.5 m tall, 2.5 x 5 cm welded wire and covered tops with 5 x 5 cm plastic mesh to exclude predators and prevent captured black ducks from escaping if they flushed while trapped. I also used a permanent 6-rocket net site and portable 3-rocket nets. I baited areas around swim-in and rocket nets with a combination of whole kernel corn, wild bird seed mix, chufa tubers, and milo beginning 15 November 2010–2011. Prior to radiomarking, I transported all captured male and female black ducks to DRU headquarters for processing.

I banded black ducks with United States Geological Survey standard aluminum tarsus bands, aged birds by wing plumage characteristics (Carney 1992, Ashley et al. 2006), and assigned a hybrid code to all black ducks according to BDJV guidelines

(BDJV 2010). I digitally photographed the dorsal and ventral side of the left wing of all females; and I measured the tarsus, middle toe, keel, head, bill, and wing chord of females for future individual morphological record. I weighed females with a 2.5-kg Pesola® spring scale (Pesola AG, Baar, Switzerland) and only instrumented females if a 23-g, harness-type, VHF transmitter (Model A1820, Advanced Telemetry Systems, Isanti, Minnesota) was <3% of an individual's body mass (Dwyer 1972, Gustafson et al. 1997). I attached transmitters to females that I deemed pure or black duck dominant x mallard hybrid (ABDU or ABDX) based on field inspection of plumage characteristics and BDJV criteria (BDJV 2010). Transmitters were equipped with mortality sensors that doubled the signal pulse rate after 8 hr of unit inactivity. After marking females, I placed them in crates and left them undisturbed for approximately one hour before returning females and males captured with them to trap sites (Cox and Afton 1998). I commenced data collection on the third day post-release to avoid short-term habitat use bias associated with transmitter adjustment (Conroy et al. 1989a, Chipley 1995).

Telemetry data collection

I determined survival status and locations of a subsample (i.e., randomly selected without replacement) of radiomarked female black ducks daily, 6 days per week (Davis and Afton 2010). I tracked the subsample diurnally and nocturnally within a 24-h cycle. I used vehicles equipped with roof-mounted, 4-element, null-peak antenna systems to track radiomarked ducks (Advanced Telemetry Systems, Isanti, MN; Cox et al. 2002, Pearse et al. 2011). I also equipped vehicles with Global Positioning System units (Trimble GeoXM™ handheld, Trimble Navigation Limited, Sunnyvale, CA), laptops with Location of a Signal software (LOAS 4.0.3.8, Ecological Software Solutions LLC,

Hegymagas, Hungary), and electronic compasses (Azimuth 1000R, KVH Industries, Middletown, RI; Cox et al. 2002, Davis and Afton 2010). I calibrated electronic compasses within $\pm 0.5^\circ$ to known locations of beacon transmitters. I trained crew members to use the tracking system and triangulate beacon transmitters until they were able to maintain a standard deviation $\leq 3^\circ$ (Davis et al. 2009, Davis and Afton 2010, Pearse et al. 2011).

Upon detecting radiomarked ducks, I recorded Universal Transverse Mercator coordinates of the tracking vehicle and ≥ 3 azimuths in LOAS to estimate locations and 95% confidence ellipses, based on a maximum likelihood estimator (Lenth 1981) and a bearing standard deviation of 3° (Davis et al. 2009, Davis and Afton 2010, Pearse et al. 2011). If necessary, I obtained additional azimuths until confidence ellipses were within one habitat type (USFWS, unpublished data) or detection vantage points were exhausted (Davis et al. 2009). If ≥ 3 azimuths were recorded, I used the combination of bearings which resulted in the smallest confidence ellipse. Additionally, I conducted aerial surveys in a Cessna 172 equipped with strut-mounted, 4-element antennas when radiomarked ducks were not detected via ground reconnaissance (Gilmer et al. 1981). I immediately investigated mortality signals and used a handheld Yagi antenna and receiver to locate and record transmitter location and document evidence related to cause of death (Cox and Afton 1998).

Statistical analysis

I used the R (v. 3.0.1; R Development Core Team 2014) package Rmark (v. 2.1.5; Laake and Rexstad 2013) to construct known-fate models in program MARK (v. 7.1; White and Burnham 1999) to estimate survival rates of radiomarked female black ducks

and explain variation in rates relative to measured covariates. I modeled winter survival from 11 December 2010–17 March 2011 (30 encounter occasions) and 19 December 2011–1 April 2012 (32 encounter occasions). I estimated survival rates using maximum likelihood estimation and a logit link function (White and Burnham 1999, Cooch and White 2013). I estimated survival over uneven intervals (i.e., 2–4 days) instead of daily intervals because I only was able to locate all females and determine their status (i.e., alive or dead) within 2–4 days. I excluded mortalities that occurred ≤ 4 days post-radiomarking from survival analyses to avoid mortality bias associated with capture and radiomarking (Cox and Afton 1998, Dooley et al. 2010a).

Explanatory variables

I modeled covariates that included year (winter 2010–2011 [year 1] or 2011–2012 [year 2]), female age (hatch year [HY] or after hatch year [AHY]), regression residuals of body mass at capture on date of capture (Lancaster 2013), hunting period (a dummy variable for each day coded as 0 = not legal hunting and 1 = hunting allowed), and weather (minimum temperature [$^{\circ}$ C], precipitation [mm], snowfall [mm], and a Weather Severity Index (WSI; Schummer et al. 2010). I acquired weather data from the National Oceanic and Atmospheric Administration’s National Climatic Data Center (<http://gis.ncdc.noaa.gov/map/ncs/>) for the Global Historical Climatology Network-Daily (GHCND) weather station in Camden, TN (GHCND:USC00401352; 14.5 km west/northwest of DRU). In the following paragraphs, I provide reasons for selection of explanatory variables used in survival models.

Body condition indices of waterfowl can vary by season, species, sex, and among populations (Miller 1989, Sparling et al. 1992). Schamber et al. (2009) recommended

using body mass alone instead of unverified indices because adjustment with a structural measurement often provides little improvement for prediction of body fat than body mass alone. White (1994) concluded that body mass adjusted by structural measurements was of little value for predicting body fat of black ducks at TNWR. I also did not adjust body mass to account for corn and other bait remaining in the crop, which may hold up to 119.5 g for a black duck (Albright 1981, Conroy et al. 1989a). However, because all traps and rocket nets were baited, I assumed that presence of corn in the crop was random among birds and thus did not bias my analysis.

Additionally, waterfowl experience endogenous changes in body mass throughout winter (Hepp 1986, Loesch et al. 1992). Because I captured and measured body mass of females from 11 December–3 February each winter, I accounted for endogenous changes in mass by evaluating linear and polynomial regression models of body mass at capture unadjusted by structural measurements on date of capture and used the residuals from the best model in my survival analyses (Lancaster 2013). I used analysis of variance to compare null (i.e., intercept only), linear, and polynomial regression models relating body mass at capture to date of capture for each year. When evaluating regression models of body mass at capture (m) on date of capture (d), I detected an interaction between date and year of capture on body mass at capture by analysis of covariance ($F_{3,109} = 7.3$, $P < 0.001$). Therefore, I determined the best model for each year separately. I neither detected an effect of age ($P = 0.77$) nor an interaction of age by date of capture ($P = 0.84$) on body mass at capture, so I did not include models incorporating age in subsequent comparisons of regression models. For winter 2010–2011, neither linear ($P = 0.87$) nor polynomial ($P = 0.48$) regression models explained variation in body mass better than the

null model ($m = 1201 - 0.1d$). For winter 2011–2012, a second-order polynomial regression model ($m = 1426 - 19.6d + 0.3d^2$) fit better than null ($P < 0.001$) or linear ($P < 0.002$) models; however, a third-order polynomial regression model did not fit better than the second-order model ($P = 0.33$). Based on these analyses, I used residuals from the null model for winter 2010–2011 and the second-order polynomial regression model for winter 2011–2012. Once the most appropriate model was identified, I used Fligner-Killeen and Shapiro-Wilk tests to test for homogeneity of variances and normality of residuals, respectively (Crawley 2013).

In addition, I modeled the effects of weather and hunting on survival by including covariates for precipitation, minimum temperature, snowfall, WSI, and hunting period. I retrieved any data missing from the Camden weather station from the GHCND weather station in Mt. Moriah, TN (GHCND:USC00406330; 7.2 km west of DRU). Despite the Mt. Moriah station being closer to DRU than the Camden station, I did not use the Mt. Moriah data because that station had more missing observations than the Camden station. I acquired mean daily temperature data for the Camden weather station from the Southern Regional Climate Center (Louisiana State University, Baton Rouge, LA). I estimated missing mean daily temperature values ($n = 2$ of 200 days) by using the median between 2 dates for which data existed. Because each interval over which survival was estimated represented multiple days, I used the mean value of daily weather covariates for each interval. I calculated WSI for each day (Equation 1.1, Schummer et al. 2010), and subsequently calculated the mean WSI value of each interval.

$$\text{WSI} = -(\text{mean daily temp}) + (n \text{ of consecutive days of mean temp } \leq 0^\circ\text{C}) + (\text{snow depth}) + (n \text{ consecutive days with snow cover}) \quad (1.1)$$

I standardized all covariates to facilitate maximum likelihood estimation (Equation 1.2; Franklin 2001, Cooch and White 2013) and examined for correlation amongst them using Pearson's product-moment correlation test.

$$\frac{x_i - \bar{x}}{SD} \quad (1.2)$$

The covariates TMIN and SNOW were correlated ($r = -0.31$, $P = 0.013$), so I did not include them together in any models. I did not detect a correlation between WSI and PRCP ($r = -0.12$, $P = 0.36$), so I included them together in models. Finally, hunting occurred daily from 4 December 2010–30 January and 3 December 2011–29 January 2012, and I coded each interval during those periods as hunted (i.e., HUNT = 1). Youth hunts occurred on 5–6 February 2010 and 4–5 February 2011, which meant that one interval in each year included 2 days that were hunted and 2 days that were not hunted, and I coded these intervals as hunted. I did not divide the intervals to more accurately reflect the hunting pressure because it took 4 days to record locations for all radiomarked ducks at that time.

Habitat use can influence survival of individual animals (Svårdson 1949, Fretwell and Lucas 1970, Block and Brennan 1993). Initially, one of the objectives of my study was to understand the connection between habitat selection and survival rates of radiomarked black ducks. However, I could not calculate habitat-related survival rates with several methods due to methodological considerations and data limitations. I could not determine habitat-related survival rates with a multi-state model because I did not meet the following model assumptions: 1) mortalities occur prior to movement and survival does not depend on the state being transitioned to, 2) all individuals transition at

the same time relative to the interval or the distribution of the transitions is known, and 3) no temporary emigration, as it is confounded with mortality (Joe and Pollock 2002, Cooch and White 2013). Additionally, I could not use selection coefficients from my habitat selection analysis (Chapter 2) as individual covariates in the survival models because not all individual birds were relocated a sufficient number of times to calculate third order resource selection functions (i.e., ≥ 20 locations; E. O. Garton, University of Idaho, pers. comm.). As an alternative, I considered modeling habitat-related survival by including the proportion of locations recorded in each habitat type (i.e., $n / \geq 20$ locations; emergent/scrub-shrub wetland, forested wetland, agriculture, and open water) as individual covariates in known-fate models (See Table 2.4 for qualitative comparison). However, this is not an appropriate approach because data limitations (e.g., small number of relocations for some individuals, 0% use of some habitats) can increase misclassification error rates, as with many habitat selection analyses (Alldredge and Ratti 1986, Bingham et al. 2006, Thomas and Taylor 2006). For most home range and habitat selection analyses, researchers recommend at least 30 locations per individual (Seaman et al. 1999). I had 12 mortalities ($n = 14$ total mortalities during the study) in my survival analysis and < 10 locations for 50% of individual deceased black ducks; thus, I believe my data for these individuals is not a representative sample of their habitat use and ultimately could result in biased survival estimates and model selection (Aarts et al. 2008, Fieberg and Börger 2012).

Model selection

I used an exploratory, sequential modeling approach to avoid over-fitting the data while evaluating models incorporating covariates of interest (Fleskes et al. 2007,

Amundson and Arnold 2011, Conover et al. 2011) which included: 1) age, body mass residuals, and year (AGE, MASS, YEAR), 2) hunting period (HUNT), and 3) weather (PRCP, SNOW, TMIN, WSI). Additionally, I avoided using a comprehensive, global model as the basis for model selection because only 12 mortalities occurred which would not support heavily parameterized models (e.g., global or fully time dependent models). I included age and body mass in the first step of model selection because these covariates often influence survival of waterfowl in winter (Conroy et al. 1989a, Krementz et al. 1997, Anderson 2008). I also included year in the first step because of the interaction between body mass residuals and year. I tested for effects of hunting and weather in subsequent steps to account for additional variation in survival rates of black ducks. Currently, Program MARK does not provide goodness-of-fit tests for models that contain individual covariates (Cooch and White 2013). The most parameterized models without individual covariates were not well supported by AIC_c , and attempts to assess model fit using median \hat{c} or bootstrapping procedures in Program MARK were unsuccessful. Estimates of dispersion in the model set ranged from 0.4–1.2, so I used $c = 1$ (Burnham and Anderson 2002, Zuur et al. 2009). To evaluate models, I used Akaike's Information Criterion corrected for small sample sizes (AIC_c) and Akaike weights (w_i), and ΔAIC_c (Akaike 1973, Burnham and Anderson 2002). I interpreted w_i as the probability that model i is the actual best model, and I calculated evidence ratios (w_i / w_j), which indicate the relative support for model j being the best model compared to model i (Burnham and Anderson 2002). I used RMark to perform model averaging on models with a $\Delta AIC_c \leq 2$ in the final step of model selection to account for model selection uncertainty in survival estimates (Burnham and Anderson 2002, Sillett and Holmes 2002, Laake and Rexstad

2013). Seasonal survival estimates were calculated as the product of all interval survival estimates for the period of interest, and the variance of the product was calculated using the Delta method in RMark (Cooch and White 2013, Laake and Rexstad 2013). I present 85% confidence intervals for survival and β estimates because variables that exclude zero with 85% confidence intervals are supported by model selection with AIC (Arnold 2010).

In the first step of model selection, I compared the constant (i.e., null) survival model and additive and interaction models incorporating YEAR, AGE, and MASS. The constant survival model and models with informative parameters that ranked above the constant survival model (i.e., those with less ΔAIC_c) were included in subsequent steps of model selection. The model considered the top model had a $\Delta AIC_{min} = 0$. All other ΔAIC values are relative to the top model, so $\Delta AIC_i = AIC_i - AIC_{min}$ (Burnham and Anderson 2002). I did not incorporate uninformative parameters in subsequent steps of model selection (Fondell et al. 2008, Arnold 2010). Models with uninformative parameters had one extra parameter than the top model, $\Delta AIC_c \leq 2$, deviance similar to the top model, and included the parameter-in-question but did not improve the model's ranking (Burnham and Anderson 2002, Arnold 2010). Deviance, an indication of model fit, is reported (Tables 2–4 and A1–A3) but only was used to aide in identification of uninformative parameters (Arnold 2010). I included models with HUNT in the second step and models with PRCP, TMIN, SNOW, and WSI in the third step, in addition to CONSTANT and those models supported from previous steps.

Results

Capture of and bait-site use by radiomarked females

I radiomarked 113 female black ducks at the DRU during winters 2010–2012 and obtained 3,834 locations and associated 95% confidence ellipses (Table 2.1). The mean percentage of an individual's locations that occurred ≤ 100 m from a permanent or mobile bait site was $5 \pm 0.71\%$. Additionally, of the 113 radiomarked females, I only had 12 recapture events (10 birds) at the original or another baited trap site during >120 trap checks, indicating females were not prone to return to bait sites after capture and marking and thus did not bias habitat and survival data.

Mortalities

I documented 14 (12%) black duck mortalities during the study, including 9 deaths in winter 2010–2011 and 5 in 2011–2012. In winter 2010–2011, I could not determine cause of mortality for 8 of 9 black ducks because I was unable to recover carcasses prior to them being scavenged by unknown animals. Additionally, 2 transmitters recovered in winter 2010–2011 were located in trees, suggesting possible raptor predation of these ducks. In winter 2011–2012, all 5 black ducks died from legal waterfowl harvest on private or public lands. These 5 ducks were killed on 10 Mile Pond Conservation Area, Missouri ($n = 2$); Camden WMA, Tennessee ($n = 2$); and private land adjacent to the Duck River, Tennessee ($n = 1$).

Survival of female black ducks

I estimated survival for 111 of 113 radiomarked female black ducks ($n = 62$, 2010–2011; $n = 49$, 2011–2012). I excluded from analyses one juvenile and one adult

female that died within 48 hours of radiomarking in winter 2010–2011. I assumed these mortalities were related to capture and radiomarking, but I was unable to examine carcasses and determine cause of mortality with certainty.

For the first step of model selection, I evaluated year, age, and mass covariates among 12 candidate models (Tables 2 and A1). The best supported model was YEAR*MASS (Table 1.2). The MASS model also ranked above the constant survival (null) model. Models with AGE were not well supported and thus not included in subsequent steps of model selection. For step 2 of model selection, I retained models from step 1 with a $\Delta AIC_c \leq 2$, which included YEAR*MASS and MASS. Also, I incorporated hunting period into a set of 8 candidate models (Tables 3 and A2). The YEAR*MASS model again was the best supported in step 2, and models retained from step 1 and HUNT*MASS ranked above the constant survival model and received some support (Table 1.3). The YEAR*MASS+HUNT model also ranked above the constant survival model (Table 1.3). However, I did not retain YEAR*MASS+HUNT in the subsequent step of model selection because it included an uninformative parameter (i.e., one extra parameter than the top model, $\Delta AIC_c \leq 2$, deviance similar to the top model, and including HUNT did not improve the model's ranking).

In the final step of model selection, I retained YEAR*MASS, MASS, and HUNT*MASS models from step 2 and incorporated daily weather covariates into a set of 44 candidate models (Tables 1.4 and A3). Weather covariate models were not well supported, and weather parameters neither improved ranking of models nor knowledge derived from them. The best supported model was YEAR*MASS, yet considerable uncertainty existed among competitive models (i.e., $\Delta AIC_c \leq 2$). The YEAR*MASS

model only had 13% of the total Akaike weight (Tables 1.4 and A3). The evidence ratios indicated that YEAR*MASS was 2.7 times more likely than MASS, 2.9 times more likely than HUNT*MASS, and 3.1 times more likely than the null model to be the actual best model (Tables 4 and A3). Thus, I incorporated this uncertainty into survival estimates by model averaging YEAR*MASS, MASS, HUNT*MASS, and the null model. Estimated survival rates for radiomarked female black ducks during the hunting season were 0.904 (85% CI = 0.840, 0.968) for winter 2010–2011 and 0.908 (85% CI = 0.857, 0.959) for winter 2011–2012 (Figure 1.6). During the non-hunting season, estimated survival rates were 0.936 (85% CI = 0.886, 0.986) for winter 2010–2011 and 0.909 (85% CI = 0.848, 0.970) for winter 2011–2012 (Figure 1.6). Overall, winter survival rates were 0.846 (85% CI = 0.746, 0.947) in 2010–2011 and 0.826 (85% CI = 0.728, 0.923) in 2011–2012.

Results from the YEAR*MASS model alone indicated the effect of body mass at capture on survival of female black ducks varied by year. Although there was no significant difference in survival between years ($\beta_{YR2} = -0.196$, 85% CI = -1.272, 0.881), there was a significant positive effect of body mass on survival in winter 2010–2011 ($\beta_{MASS} = 1.303$, 85% CI = 0.553, 2.053) and a significant negative interaction of body mass and survival in winter 2011–2012 ($\beta_{YR2:MASS} = -1.511$, 85% CI = -2.454, -0.567; Figure 1.3). Weather conditions in winter 2010–2011 generally were more severe (e.g., colder temperatures, less precipitation in early and mid-winter, and greater snowfall) than in winter 2011–2012 (Table 1.5). Amidst harsher environmental conditions in winter 2010–2011 than 2011–2012, black ducks with below average mass at capture apparently experienced decreased survival (Figure 1.3), despite not detecting effects of weather or

year on survival of black ducks. I also did not detect an effect of age on survival. Results from the MASS model indicated a weak positive effect of body mass on survival overall ($\beta_{\text{MASS}} = 0.473$, 85% CI = -0.002, 0.948; Figure 1.4). Additionally, results from the HUNT*MASS model indicated that the effect of body mass varied by hunting period (i.e., hunting or no hunting). Although there was not a significant difference in survival between hunting and non-hunting periods ($\beta_{\text{HUNT}} = -1.015$, 85% CI = -2.273, 0.244), there was a significant positive effect of body mass on survival during non-hunting periods following the closure of the hunting season ($\beta_{\text{MASS}} = 1.488$, 85% CI = 0.523, 2.453) and a significant negative interaction between periods and body mass ($\beta_{\text{HUNT:MASS}} = -1.432$, 85% CI = -2.433, -0.331; Figure 1.5).

Discussion

Winter survival estimates for female black ducks in western Tennessee (0.83–0.85) were greater than or comparable to estimates from other recent studies of radiomarked dabbling ducks, ranging from 0.54 to 0.66 for mallard (Dooley et al. 2010a, Davis et al. 2011) and 0.31 to 0.93 for northern pintail (*Anas acuta*; Cox et al. 1998, Moon and Haukos 2006, Anderson 2008). More importantly, survival rates in my study exceeded those of other black duck populations in North America. Survival rates for black ducks during the nonbreeding period (i.e., postfledging, fall migration, and wintering) have ranged from 0.49 to 0.66 in the Mississippi Flyway (Robb 1997) and from 0.37 to 0.77 in the Atlantic Flyway (Conroy et al. 1989a, Longcore et al. 1991, Longcore et al. 2000a). My survival estimates are similar to those of Chipley (1995), who radiomarked female black ducks at TNWR in the mid-1990s. Peak number of black ducks observed at TNWR declined >80% since 1990 (35,200 in January 1990 to 6,352 in

January 2010); moreover, survival rates also declined over these decades (0.94 and 1.0, Chipley 1995; 0.85 and 0.83, this study) but remained high overall. When considering Chipley's (1995) survival estimates, I emphasize that a shorter hunting season (i.e., 30-day) was in effect then and radiomarking did not commence until after the hunting season, possibly explaining in part the increase in survival between periods. Although I did not assess food acquisition by or body composition of black ducks in my study, White (1994) suggested that female black ducks may have greater winter survival in western Tennessee because of increased energy reserves compared to black ducks wintering elsewhere.

Body mass is often used as an index of an individual's energy reserves and overall condition (Johnson et al. 1985, Labocha and Hayes 2012). I found survival generally increased as body mass at capture increased, indicating that ducks with greater energy reserves have greater overwinter survival. For example, a bird of average body mass had 0.64% lower interval survival than a bird 100 g heavier on the same date of capture, or about 18% greater winter survival for the heavier bird. Though I cannot test for bias possibly induced by black ducks' association with baited trapping sites, few recaptures and relocations in close proximity (100 m) to these sites suggest survival was not biased by birds foraging on bait or using those sites. Additionally, traps were established in areas where black ducks were observed foraging, and corn was available through most of the winter in other areas of DRU. Thus, my results corroborate findings of several studies that reported ducks with lower body masses or condition indices having lower survival probabilities (Conroy et al. 1989a, Longcore et al. 1991, Bergan and Smith 1993, Davis et al. 2011).

However, I also found the effect of body mass on survival differed between winters of the study. In terms of my sample of radiomarked females, black ducks with below average body mass had lower survival than those with above average body mass during severe winter conditions (winter 2010–2011). For example, a duck with a body mass 100 g above average had an increase of 0.003 in survival probability compared to a duck with average body mass on the same date of capture, or about 9% greater survival for the heavier bird. Conversely, ducks with below average body mass had similar survival to those with above average body mass during mild winter conditions (winter 2011–2012), although overall survival did not differ significantly between years.

My best supported model, YEAR*MASS, also revealed that radiomarked black ducks with above average body mass had slightly lower survival than ducks with below average body mass in winter 2011–2012. For example, a duck 100 g heavier than one of average body mass had a 0.001 decrease in survival probability on the same date of capture, or about 3% lower survival for the heavier bird. Robb (1997) reported a similar trend for radiomarked black ducks in Ohio and speculated that ducks with greater body mass ventured more frequently away from sanctuaries into areas with increased hunting risk. Model-averaged results from my study indicated slightly lower survival for ducks with above average body mass during hunting season in winter 2011–2012, but movement data from my study does not appear to support Robb's (1997) hypothesis.

Lower survival for ducks with above average body mass may be related to the idea of optimal body mass for wintering birds and the trade-off between minimizing predation and starvation risk (Lima 1986, Rogers 1987, Conroy et al. 2002*b*). While it is energetically less costly for leaner birds to maintain fat reserves and therefore minimize

exposure to predators during foraging, these birds will have smaller fat reserves available to sustain them through fluctuations in food availability (Lima 1986, Rogers 1987). Conversely, heavy birds will have greater reserves but may have greater exposure to or decreased capability to escape from predators (Lima 1986, Rogers 1987). Thus, an intermediate body mass that minimizes the risks and maximizes the benefits is optimal for overwintering birds (Lima 1986, Rogers 1987). However, optimal body mass is thought to decrease if resources are predictable (Rogers 1987). A decrease in optimal body mass and thus lower survival for heavier ducks may have been related to greater resource predictability in winter 2011–2012 because of milder temperatures and greater precipitation than in winter 2010–2011. Alternatively, my results may be related to food availability within the sanctuary of DRU during winter (M. Gray, University of Tennessee, unpublished data). Hunting pressure surrounding the DRU contributes to fewer movements of waterfowl off the DRU during the hunting season, which increases demand for available resources on the DRU. Black ducks with below average body mass may be able to sustain themselves until hunting-related risks have passed, as it is less energetically costly to maintain a lower body mass; whereas depleting food resources on the DRU may necessitate exposure of ducks with above average body mass to hunting-related risks when seeking food (Loesch et al. 1992, Keller et al. 2009).

A direct link between survival and winter weather is difficult to demonstrate empirically (Conroy et al. 1989*a*, Longcore et al. 1991, Dooley et al. 2010*a*, but see Robb 1997) because of complicated indirect effects of weather on survival of wintering ducks (Gunnarsson et al. 2012). Winter weather severity can impact habitat use, movements, food availability, behavior, and thus indirectly survival of waterfowl (Smith and Prince

1973, Bennett and Bolen 1978, Nichols et al. 1983, Jorde et al. 1984, Whyte and Bolen 1984, Lovvorn 1989, Sauter et al. 2010). Low survival of waterfowl with below average body mass may be from increased movements to meet energetic needs required to survive winter (Conroy et al. 1989a, Sauter et al. 2010). Indirect effects of weather (e.g., poor body condition due to decreased food availability) could also increase vulnerability of black ducks to predation or other sources of mortality (Todd et al. 1982, Albright et al. 1983). Despite not detecting a statistical effect of weather on survival of black ducks, which may be partially explained by few mortalities during the study, I did observe almost twice as many mortalities during a winter with harsh weather (2010–2011) than a winter with mild weather (2011–2012).

I documented little evidence of predation of radiomarked black ducks in winters 2010–2012. I did not quantify densities or locations of predators in my study, yet predators may influence survival of wintering black ducks directly through depredation and indirectly by restricting access to critical resources. I recovered one black duck carcass in winter 2010–2011 that had the head and breast tissue removed, which suggested possible predation by a great horned owl (*Bubo virginianus*; C. Ferrell, USFWS, personal communication.). Longcore et al. (1991) and Robb (1997) also reported predation of black ducks by great horned owls in their studies. In addition to great horned owls, bald eagles (*Haliaeetus leucocephalus*) are known avian predators of black ducks (Todd et al. 1982, Longcore et al. 1991). I observed bald eagles hunting within large flocks of waterfowl on DRU during both winters of my study. Biweekly aerial surveys of DRU conducted by TNWR biologists indicated as many as 56 bald eagles were observed in January of each winter of the study (R. Wheat, USFWS,

unpublished data; $\bar{x}_{\text{YEAR1}} = 28$ and $\bar{x}_{\text{YEAR2}} = 35$). Raccoon (*Procyon lotor*) and red fox (*Vulpes fulva*) also are known predators of black ducks (Conroy et al. 1989a, Robb 1997). During both winters of my study, raccoons caused disturbance, damage, and mortalities at trapping locations on DRU, but I did not observe any foxes or sign of them.

Previous research has also related black duck survival to exposure to hunting and birds' age at capture (Krementz et al. 1987, Krementz et al. 1988, Longcore et al. 1991). I did not detect a statistical effect of hunting period on survival of female black ducks, and models incorporating HUNT (except HUNT*MASS) were not well supported, which may be due to the small number of mortalities that occurred during my study. However, hunting was clearly a source of mortality for female black ducks in my study because all 5 mortalities in winter 2011–2012 and an additional 10 mortalities occurring outside of the study period were legally harvested. In addition, I was unable to examine most carcasses in winter 2010–2011, and thus it is possible that those birds were wounded but not recovered by hunters. I also did not detect a statistical effect of age on survival of black ducks, and models incorporating AGE were not well supported. Nonetheless, 10 of 14 mortalities (71%) recorded during my study were juvenile female black ducks, and several studies have demonstrated lower survival of post-fledging, juvenile black ducks (Krementz et al. 1987, Krementz et al. 1988, Longcore et al. 1991). Perhaps the disparity in survival between juveniles and adults decreases when hunting season commences on wintering grounds and birds regardless of age learn survival tactics (Conroy et al. 1989a).

Conclusions

My results suggest that TNWR is an important wintering area for black ducks and may buffer impacts of poor survival elsewhere because survival (83–85%) was greater

than or comparable to other populations in North America during the nonbreeding period (Conroy et al. 1989*a*, Longcore et al. 1991, Chipley 1995, Robb 1997, Longcore et al. 2000*a*). Survival rates did not differ between years or hunting and non-hunting periods, but decreased survival for ducks of below average body masses in non-hunting periods could be related to within-winter changes in food availability and movements. Food resources during the post-hunting season in late winter have been diminished greatly by foraging and decomposition (Foster et al. 2010, Hagy and Kaminski 2012), yet these resources are necessary for birds moving to search for additional resources and preparing for spring migration. A bird with below average body mass may not have the energy reserves to search outside the refuge or begin migration.

Previous studies of waterfowl have corroborated a positive relationship between body mass and survival, stating that body mass represents energy reserves (Conroy et al. 1989*a*, Longcore et al. 1991, Bergan and Smith 1993, Davis et al. 2011). Thus, birds with greater body mass have more energy reserves to help them survive fluctuations in weather and food availability during winter (Lima 1986, Rogers 1987). Additionally, I found that the influence of body mass on survival of black ducks differed between hunting and non-hunting periods and also between winters, which may be related to the idea of an optimal body mass for wintering birds (Lima 1986, Rogers 1987, Conroy et al. 2002*b*). For example, winter 2010–2011 had harsh weather, which may have decreased available resources, and I observed more mortalities and lower survival for birds with below average body mass. In contrast, winter 2011–2012 had higher temperatures and greater precipitation, which may have increased available resources, and I observed fewer mortalities and slightly lower survival for birds with above average body mass. Heavier

birds may have greater predation risk and lighter birds greater starvation risk; thus, an intermediate body mass that minimizes risks and maximizes benefits is optimal for survival of overwintering birds (Lima 1986, Rogers 1987).

Studies refining estimates of available resources on TNWR are needed to determine actual availability of food resources throughout winter, especially within strongly selected for emergent/scrub-shrub wetlands (Chapter 2). Furthermore, comparisons of resource availability and landscape-scale features among TNWR and other public and private lands may elucidate reasons for greater survival at TNWR than many other studied locations. Though survival did not differ between hunting and post-hunting periods in my study, black ducks are also exposed to hunting pressure at more northern latitudes before arriving on wintering grounds. Six black ducks radiomarked during this study were legally harvested elsewhere in the Mississippi and Atlantic Flyways prior to hunting season in Tennessee. It is not known how body mass, weather, habitat selection, or survival during one portion of the annual cycle affect black ducks during the rest of the cycle. Therefore, I suggest that potential carryover effects from migration to winter and subsequent breeding periods be investigated (Sedinger et al. 2011, Sedinger and Alisauskas 2014) for black duck populations in both flyways.

Table 1.1 Age and hybrid classification of radiomarked American black ducks (*Anas rubripes*).

	2010-2011 ^a			2011-2012 ^b		
	December	January	February	December	January	February
Adult ^c						
ABDU ^e	7	8	2	6	9	0
ABDX ^f	2	0	1	0	7	1
Juvenile ^d						
ABDU ^e	11	7	5	7	8	0
ABDX ^f	7	5	9	3	7	1

^a Captured between 11 December 2010 and 3 February 2011 ($n = 64$) on Duck River Unit of Tennessee National Wildlife Refuge.

^b Captured between 19 December 2011 and 3 February 2012 ($n = 49$) on Duck River Unit of Tennessee National Wildlife Refuge.

^c After hatch year (AHY) and after second year (ASY) ducks.

^d Hatch year (HY) and second year (SY) ducks.

^e Black duck with no hybrid characteristics according to the Black Duck Joint Venture winter banding protocol (2010).

^f Black duck dominant x mallard hybrid according to the Black Duck Joint Venture winter banding protocol (2010).

Table 1.2 Top models from first step of model selection for survival analysis of radiomarked American black ducks (*Anas rubripes*).

Model description	K^a	AIC ^{cb}	ΔAIC^c	w_i^c	Dev ^d
Year ^e * Mass ^f	4	140.62	0.00	0.360	132.60
Mass	2	142.64	2.02	0.131	138.64
Constant ^g	1	142.88	2.26	0.117	54.38

^a n parameters.

^b Akaike's Information Criteria for small sample sizes.

^c Relative likelihood of model (i) based on AIC_c value.

^d Model deviance.

^e Winters 2010–2011, 2011–2012.

^f Residual values from the best regression model of body mass of female black ducks at capture on date of capture.

^g Models ranked below the constant model (i.e., null) can be found in Table A1.

Table 1.3 Top models from second step of model selection for survival analysis of radiomarked American black ducks (*Anas rubripes*).

Model description	K^a	AIC_c^b	ΔAIC_c	w_i^c	Dev ^d
Year ^e * Mass ^f	4	140.62	0.00	0.364	132.60
Year * Mass + HUNT ^g	5	142.61	1.98	0.135	132.57
Mass	2	142.64	2.02	0.133	138.64
HUNT * Mass	4	142.76	2.14	0.125	134.74
Constant ^h	1	142.88	2.26	0.118	54.38

^a n parameters.

^b Akaike's Information Criteria for small sample sizes.

^c Relative likelihood of model (i) based on AIC_c value.

^d Model deviance.

^e Winters 2010–2011, 2011–2012.

^f Residual values from the best regression model of body mass of female black ducks at capture on date of capture.

^g Dummy variable for each day coded as 0 = not hunted and 1 = hunted.

^h Models ranked below the constant model (i.e., null) can be found in Table A2.

Table 1.4 Top models from final step of model selection for survival analysis of radiomarked American black ducks (*Anas rubripes*).

Model description	K^a	AIC_c^b	ΔAIC_c	w_i^c	Dev ^d
Year ^e * Mass ^f	4	140.62	0.00	0.138	132.60
Year * Mass + PRCP ^g	5	141.78	1.15	0.077	131.74
Year * Mass + WSI ^h	5	142.37	1.75	0.057	132.33
Year * Mass + TMIN ⁱ	5	142.49	1.87	0.054	132.45
Year * Mass + SNOW ^j	5	142.62	2.00	0.051	132.58
Mass	2	142.64	2.02	0.050	138.64
HUNT * Mass	4	142.76	2.14	0.047	134.74
Constant ^k	1	142.88	2.26	0.044	54.38

^a n parameters.

^b Akaike's Information Criteria for small sample sizes.

^c Relative likelihood of model (i) based on AIC_c value.

^d Model deviance.

^e Winters 2010–2011, 2011–2012.

^f Residual values from the best regression model of body mass of female black ducks at capture on date of capture.

^g Average precipitation value (mm) over 3-day interval.

^h Average weather severity index value over 3-day interval; developed by Schummer et al.

(2010), which incorporates mean daily temperature, snowfall, and snow depth into a single index value.

ⁱ Average minimum temperature (°C) over 3-day interval.

^j Average snowfall value (mm) over 3-day interval.

^k Models ranked below the constant model (i.e., null) can be found in Table A3.

Table 1.5 Monthly summaries of Global Historical Climatology Network-Daily weather data recorded at Camden, Tennessee, USA (GHCND station: USC00401352) for November 2010–March 2012.

	November		December		January		February		March	
	2010	2011	2010	2011	2011	2012	2011	2012	2011	2012
Days with > 0.5" PRCP ^b	4	6	1	6	2	3	5	0	5	3
Days with > 1.0" PRCP	3	4	1	2	0	1	3	0	3	1
Days with TMIN ^c ≤ 0°C	7	7	26	18	28	18	16	12	6	5 ^a
Days with TMAX ^d ≤ 0°C	0	0	3	0	5	0	5	0	0	0 ^a
Total PRCP	149.6	230.1	46.2	166.7	54.3	101.0	148.4	37.5	136.9	113.8
Total SNOW ^e	0	0	66	0	168	0	88	0	0	0 ^a
Extreme TMIN	-4.4	-4.4	-13.9	-6.7	-12.8	-7.8	-15.6	-9.4	-1.1	-0.6 ^a
Extreme TMAX	5.6	5.6	15.6	19.4	18.9	20.6	22.8	26.7	28.3	29.4 ^a
Mean TMIN	3.1	5.1	-4.1	-0.1	-4.1	-0.2	0.3	0.8	4.5	9.0 ^a
Mean TMAX	17.0	17.1	6.1	11.3	6.3	12.7	12.2	13.4	16.3	23.7 ^a
Mean TEMP ^f	10.1	11.1	1.0	5.6	1.1	6.2	6.2	7.1	10.4	16.3 ^a

^a Two days of data missing.

^b Precipitation (mm).

^c Minimum temperature (°C).

^d Maximum temperature (°C).

^e Snowfall (mm).

^f Mean monthly temperature (°C).

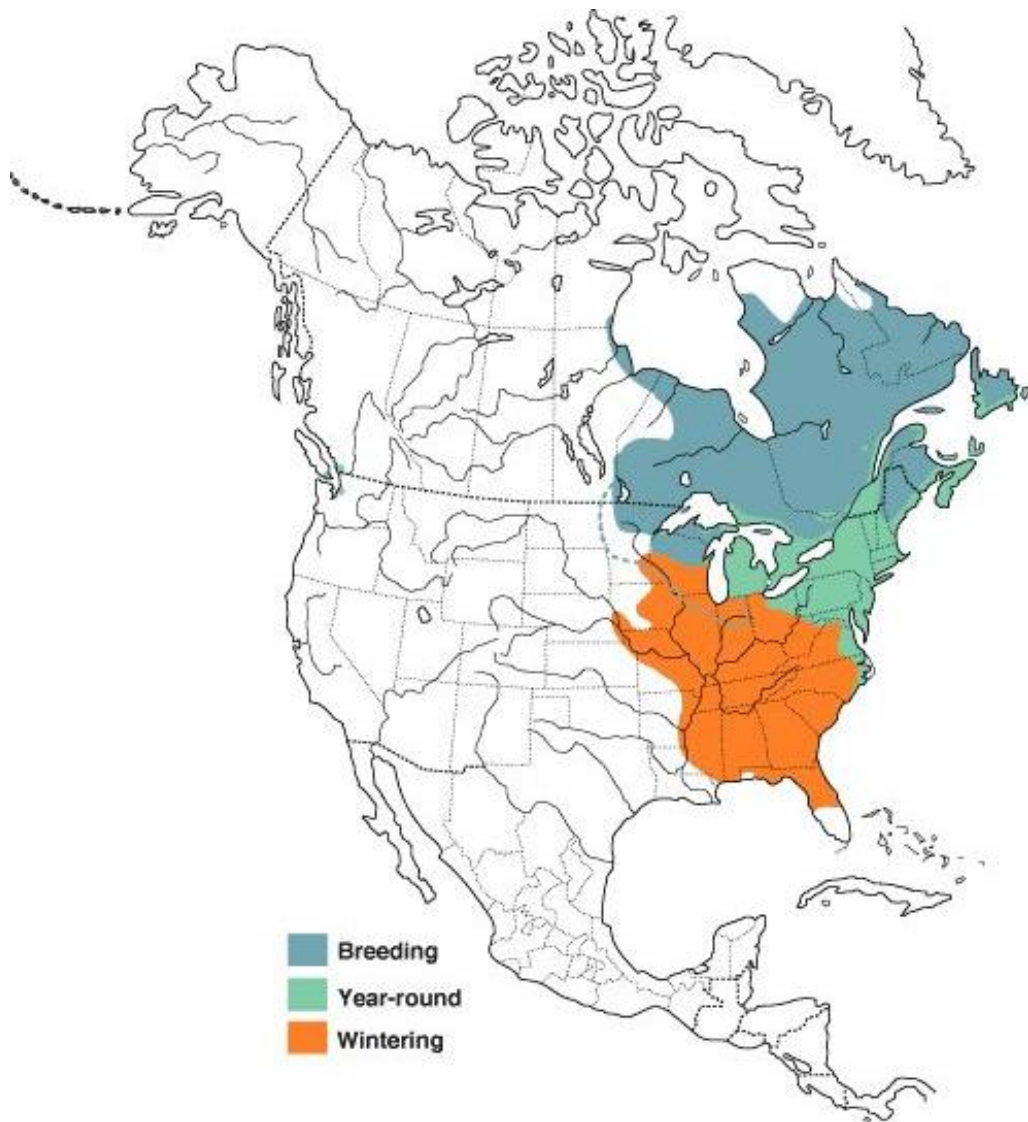


Figure 1.1 Range of the American black duck (*Anas rubripes*; Longcore et al. 2000b).

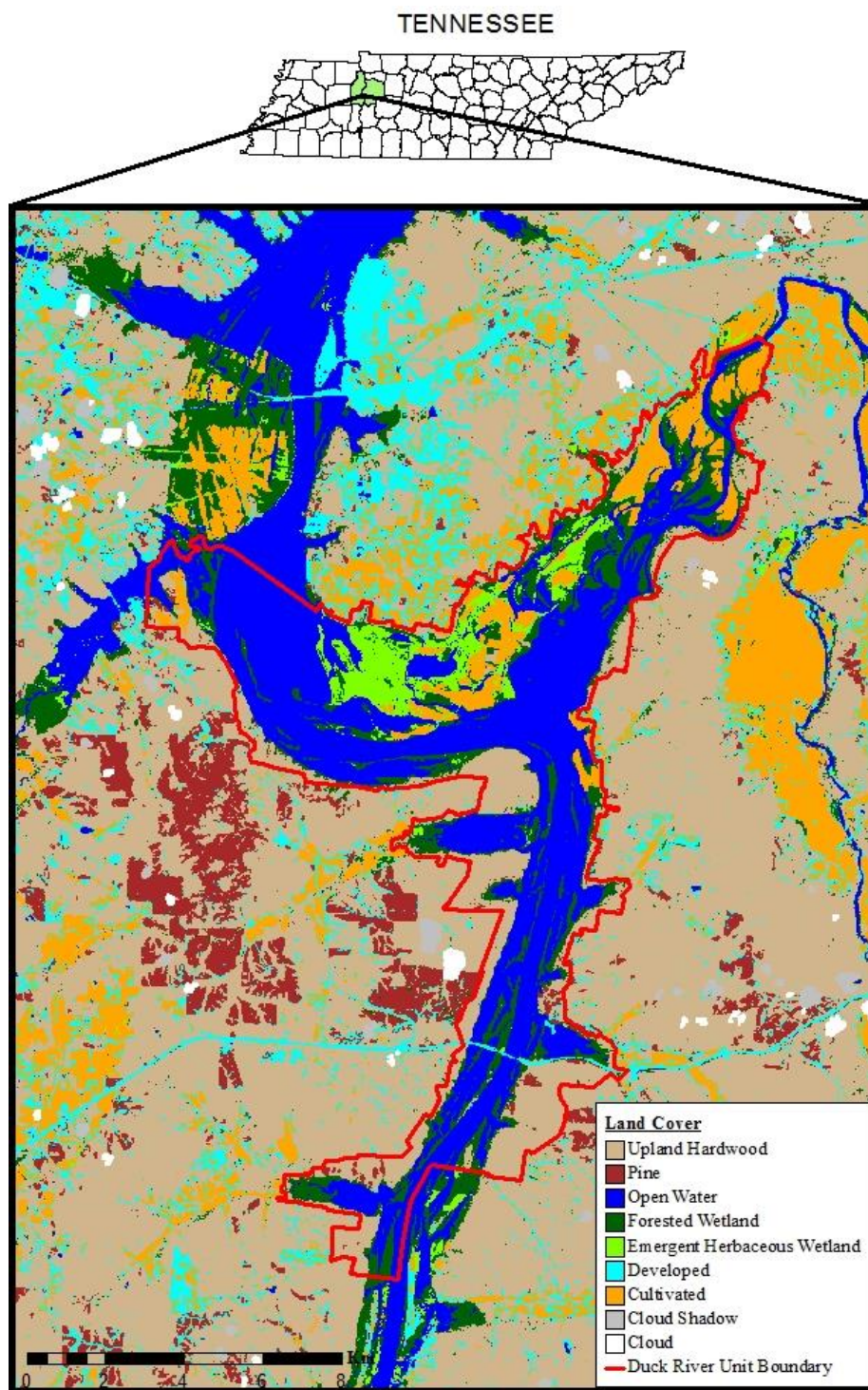


Figure 1.2 Land cover map of Tennessee National Wildlife Refuge’s Duck River Unit in Humphreys County in western Tennessee, winter 2010–2011.

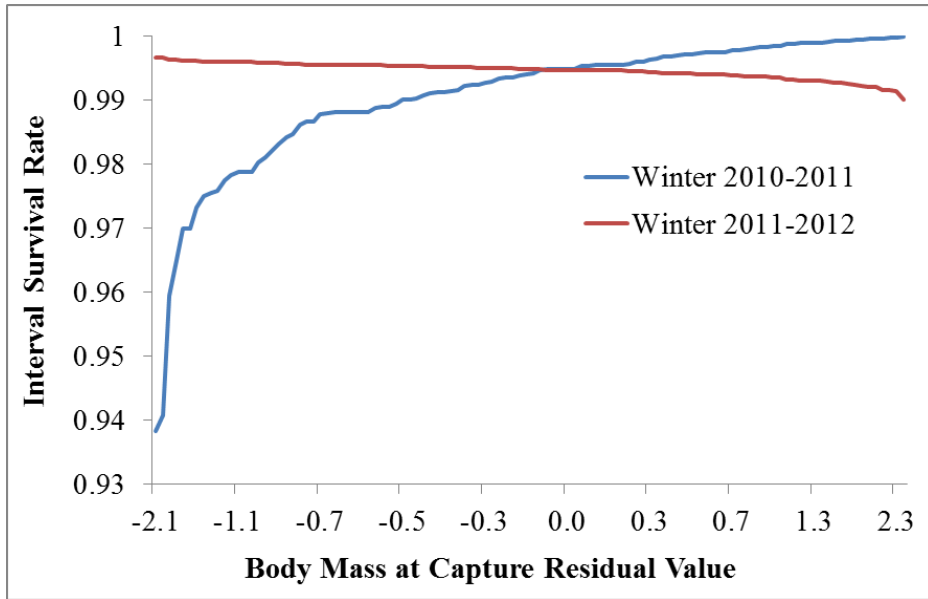


Figure 1.3 Effect of body mass at capture on survival of American black ducks (*Anas rubripes*) varies by year.

Model based estimates of 3-day interval survival rates of radiomarked females in western Tennessee during winters 2010–2011 and 2011–2012.

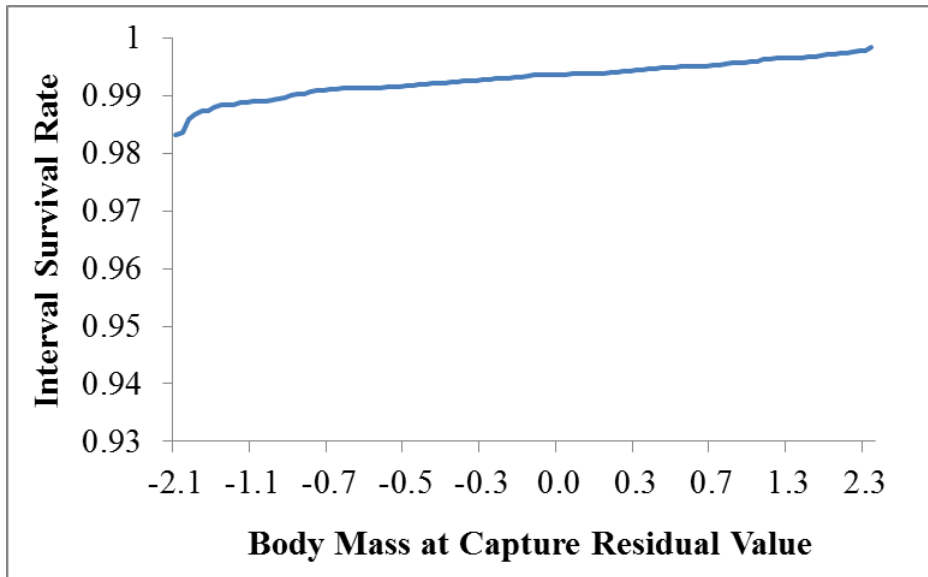


Figure 1.4 Effect of body mass at capture on survival of American black ducks (*Anas rubripes*).

Model based estimates of 3-day interval survival rates of radiomarked females in western Tennessee during winters 2010–2012.

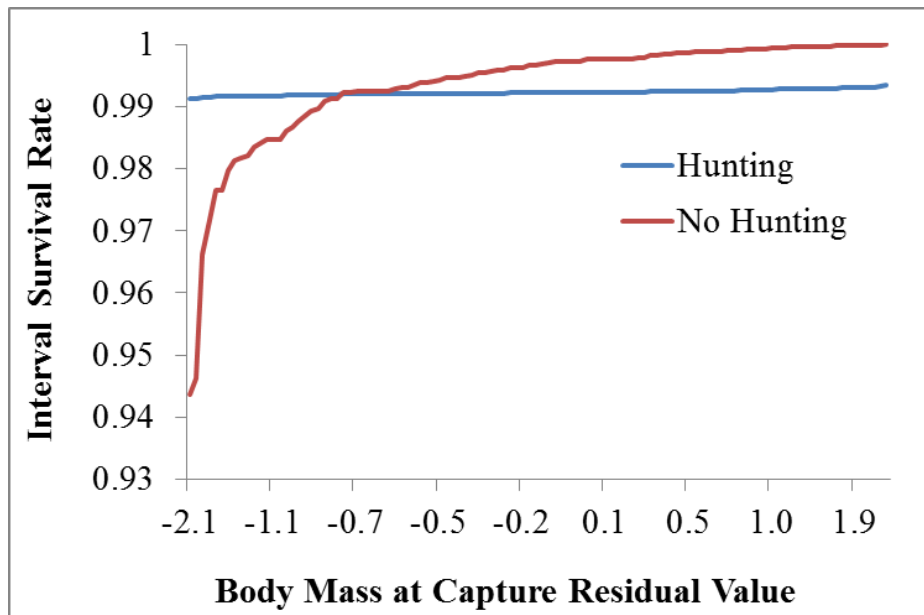


Figure 1.5 Effect of body mass at capture on survival of American black ducks (*Anas rubripes*) varies by hunting period.

Model based estimates of 3-day interval survival rates of radiomarked females in western Tennessee during winters 2010–2012.

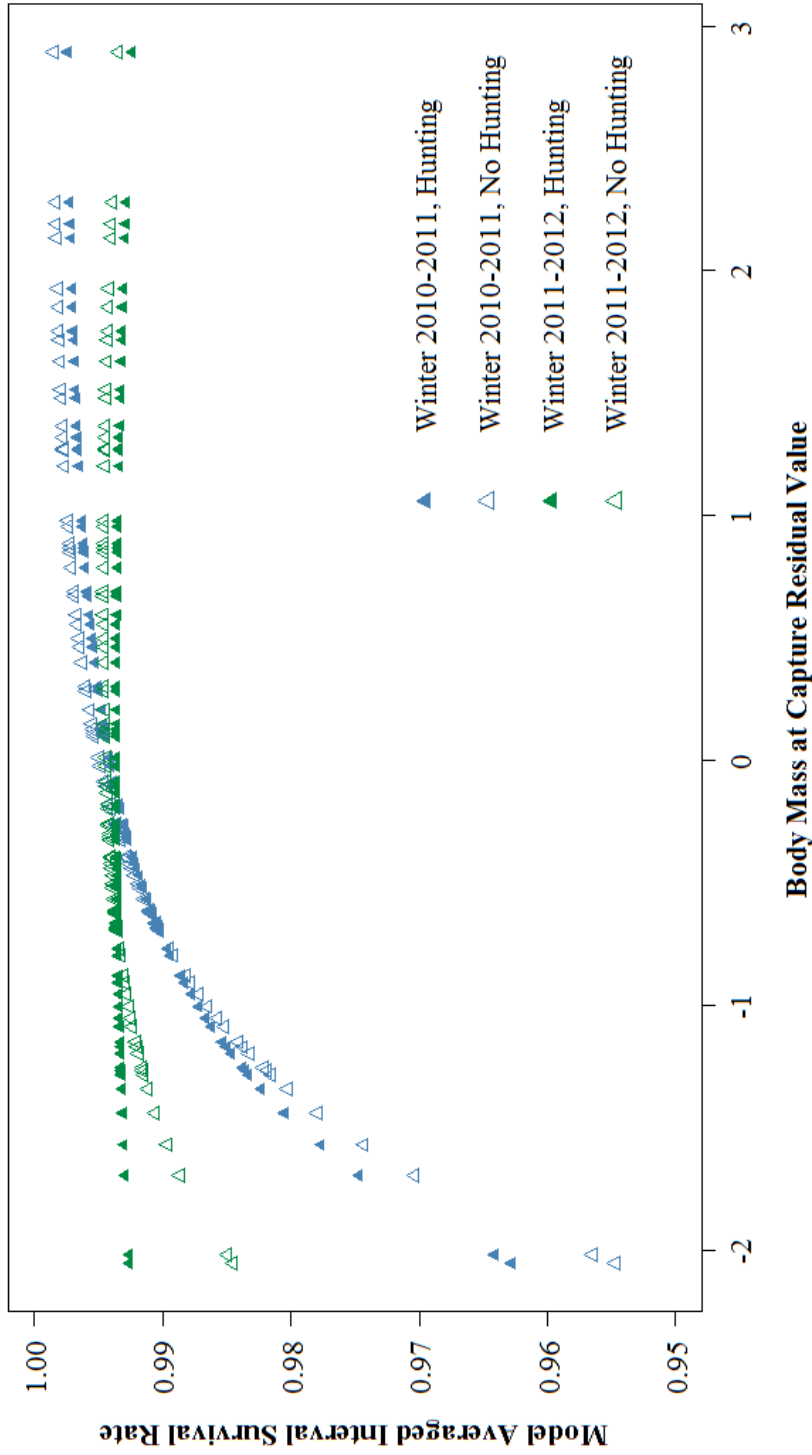


Figure 1.6 Model averaged survival rates of radiomarked female American black ducks (*Anas rubripes*) in western Tennessee, winters 2010–2012.

Determined by model averaging 3-day interval survival estimates from YEAR*MASS, HUNT*MASS, MASS, and the constant survival model.

CHAPTER II
HABITAT SELECTION BY FEMALE AMERICAN BLACK DUCKS IN TENNESSEE
DURING WINTER

Introduction

Food, water, cover, and disturbance-free areas are essential resources for waterfowl, especially during fall migration and winter when weather and waterfowl recreational seasons may limit resource availability (Reinecke et al. 1982; Whyte and Bolen 1984; Robb et al. 2001; Dooley et al. 2010*a,b*; Legagneux et al. 2009). Resource selection is the disproportionate use of available resources at some specified scale during a period of interest (Johnson 1980, Manly et al. 2002, Lele et al. 2013, Kaminski and Elmberg 2014). Understanding resource use and selection by wintering waterfowl, such as the American black duck (*Anas rubripes*; hereafter black duck) that is declining in some Nearctic regions, is necessary to elucidate patterns of bird distribution, movement, survival, and interactions among birds and habitats (Lack 1933, Moore 1945, Svårdson 1949, Jones 2001, Lele et al. 2013). Waterfowl should select habitats that provide resources necessary for them to complete winter activities such as foraging, thermoregulation, courtship, avoidance of predators and disturbance, and ultimately enhance survival (Jorde et al. 1984, Longcore and Gibbs 1988, Casazza et al. 2012, De La Cruz et al. 2014). Habitat selection by waterfowl also can be influenced by time of day, hunting season, management of habitats, and human disturbance (Davis et al. 2009,

Dooley et al. 2010*b*, Casazza et al. 2012, Coates et al. 2012, St. James et al. 2013). Thus, wetland managers require reliable knowledge of habitat selection to refine management schemes to meet needs of species in winter.

Black ducks experienced steep population declines between the 1950s and 1990s (Conroy et al. 2002*a*, Devers and Collins 2011, Klimstra and Padding 2013); however, population estimates from core breeding areas in eastern Canada appear to have stabilized (United States Fish and Wildlife Service [USFWS] 2014*a*). Possible factors contributing to declines have been debated for decades (Rusch et al. 1989, Conroy et al. 2002*a*), and harvest and hunting-related disturbance and loss and degradation of habitat are among the most implicated (Rusch et al. 1989, Nudds et al. 1996, Conroy et al. 2002*a*). The mid-continent population of black ducks in the Mississippi Flyway has continued to decline, with a 4-fold decrease (86,807 to 19,700) in the Mid-winter Waterfowl Survey (MWS) index since 1990. However, black duck abundance increased from 228,749 to an estimated 269,000 in the Atlantic Flyway during the same period (Fronczak 2012, Klimstra and Padding 2013, USFWS 2014*a*).

Historically, Tennessee National Wildlife Refuge (TNWR) in west-central Tennessee wintered the most black ducks in Tennessee and a significant portion of black ducks in the Mississippi Flyway; however, TNWR only had about 30% of the state's and 7–8% of the flyway's black ducks on the 2012 and 2013 MWS (Klimstra and Padding 2013; R. Wheat, USFWS, unpublished data). Despite the importance of TNWR and other sites in Tennessee and Ohio to wintering black ducks, little published information exists for this species in interior wetlands of the Mississippi Flyway during winter (Rusch et al. 1989, Conroy et al. 2002*a*).

Chipley (1995) studied habitat selection of radiomarked female black ducks at TNWR in winters 1990–1992 and found that birds selected palustrine emergent wetlands and lacustrine areas, while lacustrine areas in Kentucky Reservoir and agricultural areas were typically avoided. Chipley (1995) also reported that habitat selection of black ducks differed between early and late winter and diurnal and nocturnal periods. Nearly two decades have elapsed since Chipley’s (1995) study, and contemporary knowledge of habitat selection by black ducks of this declining population was needed. Thus, I studied habitat selection by female black ducks at TNWR and surrounding public and private lands during winters 2010–2012. While use of a habitat does not necessarily imply resource quality or effects on biological outcomes such as body condition and survival, understanding patterns of use in relation to available habitat provides important insight into selection or avoidance patterns exhibited by birds (Van Horne 1983). My objectives were to 1) evaluate biological and anthropogenic (i.e., human-related disturbance) factors that may influence habitat selection of radiomarked female black ducks in and near TNWR and 2) identify general patterns of habitat use which might benefit black ducks of the mid-continent population wintering in Tennessee and elsewhere in the Mississippi Flyway.

Study Area

My primary study area was the Duck River Unit (DRU; 35°57’30 N, 87°57’00 W) of TNWR in west-central Tennessee (Figure 1.2). The DRU is the largest (10,820 ha) of 3 wetland complexes comprising TNWR (20,784 ha). Primary habitats on the DRU include: 1) seasonally flooded, emergent herbaceous (i.e., moist-soil) wetlands (594 ha), 2) cooperatively farmed row crop agriculture (673 ha), 3) impounded open water (537

ha), 4) wooded sloughs, scrub-shrub, and hardwood bottomlands (2,016 ha), 5) uplands dominated by oak and hickory (*Quercus* spp., *Carya* spp.; 2,468 ha), and 6) portions of Kentucky Reservoir (3,458 ha) and the Duck River (777 ha). Agricultural crops grown at TNWR include corn, soybeans, millet, grain sorghum, winter wheat, and clover. Interior levees divide the DRU into 14 managed impoundments, and an outer perimeter levee helps protect impoundments from flooding by Kentucky Reservoir and Duck River. Waterfowl hunting is not permitted on TNWR, but hunting occurs on surrounding private and public lands. Most roads within DRU are closed to public foot and vehicular traffic from 15 November–15 March annually.

Methods

Trapping and transmitter attachment

I trapped black ducks at DRU from November through early February 2010–2012. I deployed swim-in traps where I consistently observed black ducks from ground vantage sites. I constructed traps of 1.5 m tall, 2.5 x 5 cm welded wire and covered tops with 5 x 5 cm plastic mesh to exclude predators and prevent captured black ducks from escaping. I also used a permanent 6-rocket net site and portable 3-rocket nets to capture black ducks. I baited areas around swim-in and rocket nets with a combination of whole kernel corn, wild bird seed mix, chufa tubers, and milo beginning 15 November 2010–2011. Prior to radiomarking, I transported all captured male and female black ducks to DRU headquarters for processing.

I banded all black ducks with United States Geological Survey standard aluminum tarsus bands, aged birds by wing plumage characteristics (Carney 1992, Ashley et al. 2006), and assigned a code to all black ducks indicating their degree of

hybrid plumage characteristics according to BDJV guidelines (BDJV 2010). I digitally photographed the dorsal and ventral side of the left wing; and I measured the tarsus, middle toe, keel, head, bill, and wing chord of females for future reference. I weighed females with a 2.5-kg Pesola® spring scale (Pesola AG, Baar, Switzerland) to ensure transmitters were <3% of body mass (Gustafson et al. 1997). I fit 23-g, harness-type, VHF transmitters (Model A1820, Advanced Telemetry Systems, Isanti, Minnesota) to female ducks (Dwyer 1972). I attached transmitters to female black ducks that I deemed pure or black duck dominant x mallard hybrid (ABDU or ABDX; BDJV 2010). Transmitters were equipped with mortality sensors that doubled the signal pulse rate after 8 hrs of inactivity. After captured ducks were processed, I returned them to crates and left them undisturbed for approximately one hour before returning males and females to their capture sites and releasing them (Cox and Afton 1998). Although I closely monitored females after release, I commenced data collection on the third day post-release to avoid short-term habitat use bias associated with adjustment to transmitters (Conroy et al. 1989*a*, Chipley 1995).

Telemetry data collection

I determined survival status and habitat locations of a subsample (i.e., randomly selected without replacement) of radiomarked female black ducks daily, 6 days per week (Davis and Afton 2010). I tracked the subsample diurnally and nocturnally within a 24-h cycle. I used vehicles equipped with roof-mounted, 4-element, null-peak antenna systems to track radiomarked ducks (Advanced Telemetry Systems, Isanti, MN; Cox et al. 2002, Pearse et al. 2011). I also equipped vehicles with Global Positioning System units (Trimble GeoXM™ handheld, Trimble Navigation Limited, Sunnyvale, CA),

laptops with Location of a Signal software (LOAS 4.0.3.8, Ecological Software Solutions LLC, Hegymagas, Hungary), and electronic compasses (Azimuth 1000R, KVH Industries, Middletown, RI; Cox et al. 2002, Davis and Afton 2010). Accuracy of electronic compasses was $\pm 0.5^\circ$ according to the manufacturer. I calibrated electronic compasses to known locations of beacon transmitters, and I trained crew members to use the tracking system and triangulate beacon transmitters until they were able to maintain a standard deviation $\leq 3^\circ$ (Davis et al. 2009, Davis and Afton 2010, Pearse et al. 2011).

Upon detecting a radiomarked duck, I recorded Universal Transverse Mercator coordinates of the tracking vehicle and ≥ 3 azimuths in LOAS to estimate locations and 95% confidence ellipses, based on a maximum likelihood estimator and a bearing standard deviation of 3° (Lenth 1981, Davis et al. 2009, Davis and Afton 2010, Pearse et al. 2011). If necessary, I obtained additional azimuths until confidence ellipses were within one land cover category or detection vantage points were exhausted. If more than 3 azimuths were recorded, I used the combination of bearings which resulted in the smallest confidence ellipse (Jackson et al. 2005, Cramer 2009). Additionally, I conducted aerial surveys in a Cessna 172 equipped with strut-mounted, 4-element antennas when radiomarked ducks were not detected via ground tracking (Gilmer et al. 1981). I investigated mortality signals immediately upon detection using a handheld Yagi antenna and receiver to locate transmitters and document evidence related to cause of death (Cox and Afton 1998).

Satellite imagery classification

I created a land cover map in ERDAS Imagine 2010 (ERDAS[®], Inc., Norcross, GA) by performing supervised classification on Landsat-5 Thematic Mapper (TM)

images with 30 x 30 m resolution obtained from the USGS Earth Resources Observation and Science Center (EROS) data archives (<http://glovs.usgs.gov/>). I was unable to obtain imagery with finer resolution and thus was not able to identify smaller patches of habitat that could potentially be used by female black ducks on TNWR. I used 2 contrasting seasonal images collected on 20 August 2010 and 16 March 2011, each with 7 bands and <10% cloud cover, to aid classification of land cover types. I classified land cover into open water, forested wetland, cultivated land, emergent/scrub-shrub wetland, developed areas, upland hardwood, and pine land (Table 2.1). I was unable to distinguish between emergent herbaceous and scrub-shrub wetlands without additional spatial data to calculate height of vegetation from the imagery. However, I assumed that there were more emergent herbaceous than scrub-shrub wetlands based on data from previous studies at the DRU (Chipley 1995; M. Gray, University of Tennessee, unpublished data). To assess accuracy of land cover classification, I determined land cover type of approximately 70 random assessment points for each class ($n = 488$ assessment locations overall). I did not use ground-truthed locations to assess accuracy but instead Google Earth®, National Wetlands Inventory (NWI) data, and 2010 National Agriculture Imagery Program (NAIP) digital orthophotos to interpret land cover types (Aguirre-Gutiérrez et al. 2012). The Kappa statistic is a comparison of classification errors between the user's map and a random map and indicates the level of improvement over random classification (Lillesand et al. 2008). For accuracy assessments of classification schemes, categories with Kappa statistics of $\kappa < 0.8$ are considered to have very good agreement between user and random, but $0.4 < \kappa < 0.8$ is acceptable (Pope et al. 2005, Zohmann et al. 2013). Classification accuracy based on all assessment points was 90%

($\kappa = 0.88$), and I achieved good to moderate accuracy for each class: open water (100%, $\kappa = 1$), forested wetland (97%, $\kappa = 0.97$), cultivated (99%, $\kappa = 0.98$), emergent/scrub-shrub wetland (67%, $\kappa = 0.63$), human developed (67%, $\kappa = 0.64$), upland hardwood (100%, $\kappa = 1$), and pine (100%, $\kappa = 1$).

Habitat use and availability

Habitat selection is commonly assessed by developing resource selection functions (RSFs) using logistic regression (Manly et al. 2002, Gillies et al. 2006, Koper and Manseau 2012). Resource selection functions estimate the relative probability of use of different resources and often employ a use-availability design (Manly et al. 2002, Koper and Manseau 2012, Warton and Aarts 2013). To develop RSFs for black ducks, I used the lme4 package (v. 1.1-5, Bates et al. 2014) in R (v. 3.0.3, R Development Core Team 2014) to fit generalized linear mixed-effects models (GLMM) via maximum likelihood with a logit link and Laplace approximation (Gillies et al. 2006, Hebblewhite and Merrill 2008, Bolker et al. 2009, Godvik et al. 2009). Use of GLMM or similar methods incorporating random effects is encouraged for telemetry datasets because incorporating a random effect for individuals can account for violations of autocorrelation and independence assumptions associated with repeated observations of individuals and also unbalanced sample sizes among individuals (Gillies et al. 2006, Koper and Manseau 2012). Following a use-availability, Design II approach (Manly et al. 2002), individuals were uniquely identified and habitat availability was deemed to be the same for all individuals. Like Casazza et al. (2012) and Coates et al. (2012), I deemed this an appropriate approach because 1) black ducks are capable of long-distance daily movements and 2) black duck home ranges overlapped. Moreover, additional data

could be included in the analysis if inclusion was not contingent on sufficient sample size for calculation of home ranges using kernel methods (i.e., 30 locations per individual; Seaman et al. 1999, Carter et al. 2010).

I defined the study area by creating a polygon encompassing 99% cumulative probability distributions for bivariate normal home ranges of radiomarked individuals (Horne et al. 2008, Bakian et al. 2012, Rockhill 2013, Slaughter et al. 2013). I used Animal Space Use (v. 1.3, Horne and Garton 2009) to compare performance of 4 parametric home range models (1-mode bivariate normal, 2-mode bivariate normal, 2-mode bivariate circular, and exponential power) with an information-theoretic approach for all individuals with ≥ 20 locations (Horne and Garton 2006). The 2-mode bivariate normal and circle models were the top-ranked models for all individuals, likely because of inclusion of diurnal and nocturnal locations. However, output for the 2-mode models was incomplete (e.g., probability values all equaled zero) for most individuals, so I opted to use the simpler 1-mode bivariate normal model (Jennrich and Turner 1969) and used time of day as a covariate in my habitat selection models. Next, I used Geospatial Modelling Environment (v. 0.7.2.0, Beyer 2012) to calculate 99% probability contours for each bivariate normal home range, and I loaded contours into ArcMap™ (v. 10.0, ESRI, Redlands, CA) to create a polygon that encompassed all individual contours.

My response variable was binomially distributed with used locations of ducks assigned a value of 1 and available locations a value of 0. To quantify available locations within my study area, I generated random points in ArcMap and discarded points in pine, upland hardwood, and developed cover classes because few used locations fell within these classes ($n = 61$ of 3,816 [2%]). Next, I selected 3 times as many random points as

total number of black duck locations and assigned multiple covariate values to all points (Lele 2009, Koper and Manseau 2012, Kowal et al. 2014). My covariates of interest included habitat, refuge, distance to nearest road, hunting season, hunting time, and diel period. I designated these covariates as fixed effects, and I also included a random intercept for individuals (Gillies et al. 2006).

Explanatory variables

For the habitat covariate (HABITAT), I superimposed locations of black ducks on the land cover map and extracted attributes to locations so each was categorized as emergent/scrub-shrub wetland, forested wetland, cultivated land, or open water. High resolution imagery that would otherwise permit classification of available habitat based on daily presence or absence of water on the landscape was not available. Thus, I assumed that emergent/scrub-shrub, open water, and forested wetlands were potentially available during winter. Resource managers at TNWR and elsewhere in my study area flood emergent/scrub-shrub and forested wetlands and agricultural fields (harvested and non-harvested) during winter to provide waterfowl habitat. Based on personal observations of ducks at TNWR, black ducks and mallards foraged and rested in inundated and dry cultivated areas. Thus, I included all cultivated lands as available habitat.

To investigate effects of human-related disturbance, I created continuous and categorical covariates to represent potential disturbance related to road use (DIST_ROAD), access (REFUGE), and hunting (HUNT_SEASON and HUNT_TIME). For the continuous covariate DIST_ROAD, I merged primary and secondary roads of Tennessee (2013 TIGER/Line Shapefiles, U.S. Census Bureau,

<https://catalog.data.gov/dataset>) with TNWR's road layer and used ArcMap to calculate the distance to nearest road (m) from each duck location. For the categorical covariate REFUGE, I classified each location as whether it occurred on TNWR (REFUGE = 1) or not (REFUGE = 0). Because TNWR prohibits waterfowl hunting and restricts other public use (e.g., fishing or bird watching) until 15 March, it likely had the least amount of human-related disturbance in my study area. The waterfowl hunting seasons in my study area were 4 December 2010–30 January 2011 and 3 December 2011–29 January 2012, including youth waterfowl hunting on 5–6 February 2011 and 4–5 February 2012. I recorded locations of radiomarked black ducks either during the hunting season (HUNT_SEASON = 1) or not (HUNT_SEASON = 0). Because daylight and legal shooting hours were similar but not synonymous, I created separate categorical covariates for these designations. Legal shooting hours extend from 30 minutes before sunrise until sunset (HUNT_TIME = 1). I refer to this temporal period hereafter as legal shooting hours to be consistent, regardless of whether it was during or after waterfowl hunting seasons. I considered locations diurnal (AM = 1) if they were recorded between 30 minutes before sunrise to 30 minutes after sunset and nocturnal (AM = 0) otherwise (Casazza et al. 2012, Coates et al. 2012). I determined sunrise and sunset times from NOAA's solar calculator (<http://www.esrl.noaa.gov/gmd/grad/solcalc>). To assign hunting and time of day to available points, I randomly selected with replacement an equal number of available points ($n = 1,908$) for each possible combination of hunting season, hunting time, and time of day (Table 2.2).

Model selection and inference

I created a candidate set of 14 a priori models to investigate habitat selection by female black ducks in winters 2010–2012. Continuous covariates were standardized to facilitate maximum likelihood estimation (Equation 1.2, Zuur et al. 2009). I used Spearman rank correlations to examine collinearity among pairs of all explanatory variables because this method allows for non-linear relationships between variables (Zuur et al. 2009). I did not include variables that covaried ($r_s \geq |0.5|$) in the same models (Booth et al. 1994, Zuur et al. 2009). I evaluated model support using Akaike's Information Criterion (AIC, Akaike 1973), Δ AIC, and Akaike weights (w_i , Burnham and Anderson 2002). I assessed goodness-of-fit for the best supported model by calculating marginal and conditional coefficients of determination (pseudo- R^2) in R with the MuMIn package (v. 1.9.13; Barton 2013, Nakagawa and Schielzeth 2013). For mixed models, marginal R^2 represents the variance explained by fixed effects, and conditional R^2 represents that of fixed and random effects (Nakagawa and Schielzeth 2013).

Bayesian statistical approaches are preferred for calculating confidence intervals for GLMM parameters because they take into account variance associated with fixed and random effects (Bolker et al. 2009, Mørbæk et al. 2009). In order to calculate Bayesian credible intervals for model parameters, I refit the best supported model for each year using the R2jags package (v. 0.04-01, Su and Yajima 2014) in R to interface with JAGS (v. 3.4.0, Plummer 2003; Zuur et al. 2009, Hörnell-Willebrand et al. 2014). I specified uninformative priors for all parameters, and I used 3 chains each with 130,000 iterations, burn-in of 30,000, and thinning rate of 20 for 2010–2011 and 42,000 iterations, burn-in of 2,000, and thinning rate of 10 for 2011–2012. I examined plots of the output and ran

models until convergence occurred, which indicates that between- and within-chain variance is similar (i.e., $\hat{R} < 1.1$; Gelman et al. 2013). Additionally, I evaluated model fit by examining Bayesian p-values, which should be $0.05 < P < 0.95$ (Gelman et al. 2013).

I calculated population-level odds ratios to interpret habitat selection by female black ducks during each winter (Godvik et al. 2009, Mobæk et al. 2009). Because I could not verify if random available points were not used, absolute values of log-odds (i.e., β estimates) were meaningless (Keating and Cherry 2004, Mobæk et al. 2009). Thus, for each combination of habitat, hunting season, and temporal covariates, I summed the corresponding log-odds and took the exponent to get the odds of selection. I calculated odds of selection in the Bayesian models as derived parameters which yielded estimates and 95% credible intervals, and I interpreted my results using ratios of the odds of selection (Keating and Cherry 2004). Finally, I used parameter estimates from the best supported model to create RSFs and probability maps representing diurnal and nocturnal habitat selection of black ducks (Johnson et al. 2004).

Results

I obtained 3,816 locations of 111 radiomarked female black ducks during winters 2010–2012. My study area incorporated more area outside of TNWR (525,419 ha) than within refuge bounds, based on females use of habitats (12,143 ha; Table 2.7; Figure 2.1). Because I found significant interactions between habitat types and year (Table 2.3), I analyzed data from each year separately. I evaluated an identical set of 14 candidate models for each year; however, I excluded 2 models for winter 2010–2011 because all categories did not have locations and therefore models did not converge (Table 2.5). I

calculated odds ratios based on the log-odds of only the top model for both winters because only the top models were considered competitive ($w_i > 0.99$; Tables 2.5 and 2.6).

Winter 2010–2011

Best supported model

Of 12 candidate models, the best supported model included effects of distance to nearest road, refuge, and a 3-way interaction among habitat types, hunting season, and legal hunting hours (marginal $R^2 = 0.51$, conditional $R^2 = 0.56$; Tables 2.5 and 2.8; Figure 2.2). Black ducks had greater odds of selecting habitats on TNWR than off the refuge. Additionally, there was a weak negative effect of distance to nearest road on habitat selection; there was an 11% increase in selection probability of a location for every 100 m closer to a road locations were from the average distance for all black duck locations to the nearest road (361 m).

Model selection

The intercept only and HABITAT models were the least supported models in my candidate set (Table 2.5). When I added REFUGE to the HABITAT model, there was an increase in explained variation in habitat selection. Interactions with time of day and hunting season improved model ranking over additive and other interaction models. There was little support for the model incorporating DIST_ROAD * REFUGE, and model results indicated a non-significant interaction between these 2 covariates. Model ranking improved when I included HUNT_SEASON interactions with HABITAT and REFUGE. Models including interactions with HABITAT had greater support than the

same models with REFUGE interactions. Explained variation also increased when AM was included in interaction terms, especially with HABITAT.

Hunting season

During legal hours of the waterfowl hunting season, black ducks had 3–4 times greater odds of selecting emergent/scrub-shrub wetlands than open water, cultivated areas, or forested wetlands (Tables 2.8 and 2.10). During non-hunting hours, black ducks had even greater odds of selecting emergent/scrub-shrub wetlands over cultivated areas, open water, or forested wetlands (8.8, 15, and 52 times, respectively). Black ducks had greater odds of selecting cultivated areas, open water, and forested wetlands during legal hunting hours than non-hunting hours (1.4, 2.5, and 7 times, respectively), but emergent/scrub-shrub wetlands had 2 times greater odds of selection during non-hunting than hunting hours.

Post-hunting season

Similar to the waterfowl hunting season, black ducks had 4–5 times greater odds of selecting emergent/scrub-shrub wetlands than cultivated areas, forested wetlands, or open water after the hunting season in what would have been legal hunting hours (Tables 2.8 and 2.10). During non-hunting hours, black ducks had greater odds of selecting emergent/scrub-shrub wetlands over open water, forested wetlands, or cultivated areas (38, 42, and 96 times, respectively). Black ducks had greater odds of selecting cultivated areas, forested wetlands, and open water during hunting hours than non-hunting hours (14, 5.4, and 4.3, respectively), but emergent/scrub-shrub wetlands had 2 times greater odds during non-hunting than hunting hours of the post-hunting

season. Cultivated areas, forested wetlands, and open water had greater odds of selection during shooting hours in the post-hunting season. While black ducks consistently selected emergent/scrub-shrub wetlands in winter 2010–2011, this habitat type was most likely to be selected during non-hunting hours in the post-hunting season.

Winter 2011–2012

Best supported model

Of 14 candidate models, the best supported model included the effect of distance to nearest road and a 3-way interaction among habitat types, refuge, and time of day (marginal $R^2 = 0.27$, conditional $R^2 = 0.35$; Tables 2.6 and 2.9; Figure 2.3). Similar to winter 2010–2011, I found a weak negative effect of distance to nearest road on habitat selection; there was a 12.5% increase in selection probability of a location for every 100 m closer to a road locations were from the average distance for all black duck locations to the nearest road (361 m; Table 2.6).

Model selection

Similar to results from winter 2010–2011, I found little support for intercept only and additive models without interaction terms and also increases in explained variation with inclusion of REFUGE and temporal covariates (Table 2.6). Models with interaction terms including HABITAT had greater support than the same models with interaction terms including REFUGE, but unlike winter 2010–2011, HABITAT * HUNT_SEASON had less support than REFUGE * HUNT_SEASON. However, when HUNT_TIME was included in those interaction terms, the interaction with HABITAT had greater support than the interaction with REFUGE. Though the model with DIST_ROAD * REFUGE

was less supported than other interaction models, selection of areas near roads did differ on and off TNWR and also with time of day in winter 2011–2012.

Diurnal use

On TNWR, female black ducks had 3–5 times greater odds of selecting emergent/scrub-shrub wetlands than cultivated areas, forested wetlands, or open water (Tables 2.9 and 2.11). Black ducks had greater odds of selecting forested wetlands, emergent/scrub-shrub wetlands, open water, and cultivated areas on TNWR than off the refuge (18, 24, 38, and 60 times, respectively). Off the refuge, black ducks had greater odds of selecting emergent/scrub-shrub wetlands than forested wetlands, cultivated areas, or open water (2.7, 7.3, and 8.9 times, respectively).

Nocturnal use

On TNWR, black ducks had greater odds of selecting emergent/scrub-shrub wetlands over cultivated areas, forested wetlands, or open water (4.3, 18, and 81 times, respectively; Tables 2.9 and 2.11). Black ducks had greater odds of selecting open water, forested wetlands, emergent/scrub-shrub wetlands, and cultivated areas on TNWR than off the refuge (18, 30, 64, and 577, respectively). Cultivated areas, forested wetlands, and emergent/scrub-shrub wetlands had the greatest odds of selection on the refuge at night; however, black ducks had the greatest odds of selecting open water on the refuge during the day. Off the refuge, black ducks had greater odds of selecting emergent/scrub-shrub wetlands than forested wetlands, open water, or cultivated areas (8.3, 23, and 39 times, respectively).

Discussion

Use of habitat complexes

Waterfowl, like other birds, typically use a complex of habitats to meet their needs during winter (Southwood 1977, Nichols et al. 1983, Lewis and Nelson 1988, Pearse et al. 2012). Black ducks used all available habitat types on and off TNWR (i.e., forested and emergent/scrub-shrub wetlands, open water, and agricultural lands) during winters 2010–2012. These ducks also demonstrated greater affinity for emergent/scrub-shrub wetlands than other habitats on or off TNWR during both winters of my study regardless of hunting activity or time of day. Because I could not differentiate between emergent herbaceous and scrub-shrub wetlands throughout my study area with available satellite imagery, I also could not determine whether selection for emergent/scrub-shrub wetlands was related specifically to emergent herbaceous or scrub-shrub habitats. However, previous studies at TNWR were able to distinguish between emergent herbaceous and scrub-shrub wetlands, and they found that black ducks had greater affinity for emergent herbaceous than scrub-shrub wetlands (Chiple 1995, Clark 1996). Energetic carrying capacity was greater in emergent herbaceous wetlands than scrub-shrub or forested wetlands, and black ducks spent the majority of time foraging in emergent herbaceous wetlands but resting in scrub-shrub wetlands during winter 2011–2012 (M. Gray, University of Tennessee, unpublished data). Chiple (1995) found that female black ducks selected emergent herbaceous wetlands, especially at night, and hypothesized they used them as nocturnal roosts. Clark (1996) reported that black ducks used habitats with open water interspersed with herbaceous vegetation, whereas flooded forests and monocultural management units were used less. In addition to roosting, black

ducks may use emergent herbaceous wetlands during winter to meet nutritional needs (Brodsky and Weatherhead 1985*a*, Kaminski et al. 2003), thermoregulatory benefits (Brodsky and Weatherhead 1984, Jorde et al. 1984), and possibly predator avoidance, although research on effects of predators on wintering ducks in the United States is limited (Albright et al. 1983, Tamisier 1985, Casazza et al. 2012).

Use of sanctuaries

Designated sanctuaries are an important part of a complex of wetlands for nonbreeding waterfowl in winter, especially during hunting seasons (Conroy et al. 1987, Morton et al. 1989*a*, Guillemain et al. 2002, Casazza et al. 2012, Coates et al. 2012). As a designated waterfowl sanctuary, most of TNWR is closed to the public during winter (i.e., 15 November–15 March). Waterfowl using sanctuaries typically expend less energy because of alleviated human disturbances (e.g., hunting, boating, and bird watching), which can ultimately enhance survival (Morton et al. 1989*b*, Guillemain et al. 2002, Dooley et al. 2010*a*). Black ducks exhibited greater odds of selecting habitats on than off TNWR during winters 2010–2012. Because this selection pattern persisted regardless of habitat type, open or closure of hunting, or time of day, my results suggest the importance of TNWR for wintering black ducks may extend beyond its function as a sanctuary. However, the affinity for TNWR by black ducks may reflect a bias in habitat use resulting from capturing and marking black ducks only on DRU. Fidelity to TNWR also may have been related to the refuge's habitat quality or landscape-scale features such as wetland size, availability, and arrangement (Pearse et al. 2012, Beatty et al. 2014). Moreover, I found that black ducks selected areas closer to roads, where disturbance was more likely to occur. Black ducks may have selected habitats closer to roads and levees

because of their structural similarity to other linear landscape features, such as riverine wetlands in the boreal forest (breeding area) and coastal wetlands (wintering area), throughout the black duck's range in eastern North America. Emergent/scrub-shrub wetlands adjacent to roads, especially levees in managed areas, also may provide thermoregulatory benefits as wind-breaks and loafing platforms in addition to food for wintering waterfowl (Paulus 1988a, White 1994). In the MAV, mallards and other dabbling ducks frequently use roadside and levee ditches on refuges during winter, but only after the hunting season when risk of hunting mortality is alleviated on areas open to hunting (R. M. Kaminski, Mississippi State University, personal communication).

I observed concentrated use within managed habitats of TNWR by black ducks, most notably at night within emergent/scrub-shrub wetlands, similar to patterns observed in northern pintails in California (*A. acuta*; Coates et al. 2012). Nocturnal foraging has been documented extensively in many species of waterfowl including black ducks (McNeil et al. 1992). McNeil et al. (1992) proposed that waterfowl foraged at night because 1) energetic requirements were not met diurnally (supplementary hypothesis) or 2) greater benefits were accrued by feeding nocturnally versus diurnally (preference hypothesis). Casazza et al. (2012) explored these hypotheses relative to habitat selection by northern pintail and found northern pintails avoided hunting risk by foraging only on preferred foods outside of sanctuaries at night, which supported the preference hypothesis (Casazza et al. 2012). A similar pattern also was observed for northern pintails wintering in Louisiana (Cox and Afton 1997). Unlike sanctuaries in Suisun Marsh, DRU is a large wetland complex managed entirely as a sanctuary for waterfowl, which would allow black ducks to forage diurnally on DRU without risk from hunting. Moreover, other

human-related disturbances are minimized and assumed inconsequential on DRU, which may have been evidenced by black ducks selecting areas closer to roads. I speculate that black ducks prefer to forage in emergent/scrub-shrub wetlands at night and may incur thermoregulatory or other benefits not reconciled by my study. Additionally, previous research has suggested that waterfowl forage in emergent/scrub-shrub wetlands at night to avoid predators such as bald eagles (*Haliaeetus leucocephalus*) and other diurnal raptors (Paulus 1988a, Todd et al. 1982, McNeil et al. 1992). Moreover, nocturnal predators, including owls (e.g., *Bubo virginianus*) and raccoons (*Procyon lotor*), may be more likely to hunt in forested and non-flooded habitats than emergent/scrub-shrub wetlands (Nicholls and Warner 1972, Chamberlain et al. 2003).

Patterns related to diel and hunting cycles

In winter 2010–2011, habitat selection by black ducks was best explained by a model incorporating hunting season and daytime shooting hours, but there was little support for this model for winter 2011–2012. Black ducks were most likely to select emergent/scrub-shrub wetlands regardless of hunting season or time of day in both winters. During the hunting season in winter 2010–2011, black ducks subsequently sought open water, mostly on TNWR, during shooting hours but cultivated areas (e.g., flooded corn fields) after shooting hours. Conversely after closure of hunting season, cultivated areas were more likely to be selected during shooting hours but open water after shooting hours. Hunting-related mortality and disturbance are potential risks for black ducks outside of TNWR during winter (Krementz et al. 1988, Morton et al. 1989b, Robb 1997). By foraging in cultivated areas outside of TNWR diurnally after the hunting season and nocturnally during the hunting season in winter 2010–2011, black ducks may

have enhanced energy intake while avoiding potential mortality risks. I did not have sufficient data to determine whether this pattern differed on and off TNWR in winter 2010–2011. However, in winter 2011–2012, black ducks had much greater odds of selecting cultivated areas on TNWR than off the refuge diurnally and especially nocturnally. Black ducks may prefer to forage at night when unrestricted by human disturbance or freezing temperatures, as during winter 2010–2011 and similar to other dabbling ducks (Owen and Williams 1976, Jorde et al. 1984, McNeil et al. 1992). Corn and other waste seeds in cultivated areas provide waterfowl with high energy and easily metabolized foods that minimize energetic expenditure while foraging (Kaminski et al. 2003). Conversely, black ducks sought open water diurnally during the hunting season and nocturnally post-hunting season in winter 2010–2011. Open water was the primary habitat available during freezing temperatures in winter 2010–2011. Additionally, open water may have been used by black ducks for courtship in winter and also may have provided loafing areas with clear visibility of potential predators (Trautman 1947, Brodsky and Weatherhead 1985*b*, Paulus 1988*b*, White 1994).

Marked patterns of diel habitat selection are common in waterfowl studies (Morton et al. 1989*a*, Chipley 1995, Davis and Afton 2010, Cazassa et al. 2012, Beatty et al. 2014). While emergent/scrub-shrub wetlands consistently had the greatest odds of being selected in winters 2010–2012 regardless of hunting season or time of day, black ducks were 2–8 times more likely to select emergent/scrub-shrub wetlands nocturnally than diurnally. Selection for other habitats varied among time periods in my study, and I observed greater similarity in odds among habitats during the day than at night. While cultivated areas were the secondary selection of black ducks diurnally and nocturnally on

TNWR, they selected forested wetlands diurnally and nocturnally off TNWR in winter 2011–2012. Forested wetlands likely provided important resources such as cover, red oak (*Quercus* spp.) acorns, and aquatic invertebrates to meet ducks' nutritional and thermoregulatory needs that were unavailable in other habitats, or that may have been accessible but with greater risk elsewhere (Kaminski et al. 2003, Davis and Afton 2010).

Conclusions

Use of TNWR throughout winter by female black ducks and the birds' high winter survival rates (83–85%; Chapter I) suggest TNWR likely provides an important complex of habitats, especially emergent herbaceous and scrub-shrub wetlands, for black ducks wintering in the Tennessee portion of the Mississippi Flyway. Radiomarked black ducks also used other areas near TNWR, such as Camden Wildlife Management Area, Jarrell Switch Refuge, and private lands, but not to the extent of TNWR. Causes of decreasing numbers of black ducks wintering on TNWR could not be elucidated by my study, but other investigators have suggested declining black duck populations may be related to multiple interacting factors including landscape-scale changes in resource availability, additive hunting mortality, and competition with mallards on the breeding grounds (Conroy et al. 2002a, Petrie et al. 2012, USFWS 2014b). To study concurrent habitat use of black ducks and mallards wintering on TNWR, I also radiomarked 17 female mallards (*A. platyrhynchos*) and obtained 561 locations during winter 2011–2012. Despite spatial overlap of these species on and off TNWR at the home range scale, I cannot conclude that black ducks and mallards competed for resources at this scale. Future studies might experimentally investigate spatio-temporal use of habitats and resources by black ducks and mallards to test hypotheses about potential competition

between these species at TNWR and other wintering grounds where the species are sympatric, as has been performed on the breeding grounds (e.g., Petrie et al. 2012). Mallards used agricultural lands more than black ducks, which may reflect greater potential success for mallards than black ducks to adapt to and use agricultural lands in the Mississippi Flyway. These and other factors may have contributed to a northern shift in the wintering range of black ducks (Link et al. 2006, Brook et al. 2009). However, climate change and increasing winter temperatures also have been implicated previously in shifting distributions of waterfowl and other avian species (Godet et al. 2011, Guillemain et al. 2013, Schummer and Vanden Elsen 2013).

Though I was unable to link use of particular habitats with increases in survival because of few mortalities, a qualitative comparison of mortalities and surviving birds indicate there may be potential differences in habitat use (Table 2.4). However, greater numbers of mortalities and locations for those birds are necessary to clearly distinguish relevant patterns. Thus, I recommend future studies determine habitat-specific survival during winter for sympatric black ducks and mallards to identify “suitable” habitats for both species (i.e., those promoting survival; *sensu* Fretwell 1972), as well as identify any possible resource limitations that could be inducing competition. Additionally, I recommend continued active management of habitats, specifically nocturnal foraging and roosting sites within emergent herbaceous wetlands and cultivated areas at TNWR (Kross et al. 2008, Fleming et al. 2012). Regardless if these actions increase numbers of black ducks wintering on TNWR, waterfowl that migrate to and use the area would benefit from the refuge’s resources, especially emergent herbaceous wetlands that provide a greater complexity of vegetation structure and foods than agricultural lands (Kross et al.

2008). Because I was unable to differentiate between selection for emergent herbaceous and scrub-shrub wetlands, future studies should employ ground-truthed or high-resolution imagery with structural height data (e.g., LiDAR or IKONOS) to separate these habitats and parse out the relative importance to black ducks of proximity to scrub-shrub habitat for cover and thermoregulatory benefits. Furthermore, investigations into microhabitat characteristics within areas of black duck use on TNWR are needed to ensure similar habitats are provided where feasible in other areas of TNWR and throughout the region (M. Gray, University of Tennessee, unpublished data).

Table 2.1 Land cover classes created for supervised classification of Landsat-5 Thematic Mapper images of Tennessee taken on 20 August 2010 and 16 March 2011.

Land Cover Class	Description
Open water	Permanent water bodies lacking emergent vegetation including Kentucky Reservoir and Duck River
Forested wetland	Seasonally flooded timber
Cultivated land	Pastures, temporarily idled cropland, and agricultural fields
Emergent/scrub-shrub wetland ^a	Seasonally flooded emergent herbaceous or scrub-shrub vegetation
Developed	Homes, roads, and other man-made structures
Upland hardwood	Non-coniferous forest
Pine	Coniferous forest dominated by <i>Pinus</i> spp.

^a Emergent herbaceous and scrub-shrub wetlands were combined because these could not be differentiated with available imagery.

Table 2.2 Explanation of assignment of covariate combinations to available locations for habitat selection analyses.

Covariate	Possible Combinations ^a						Excluded ^b	
HUNT_SEASON ^c	1	1	1	0	0	0	1	0
HUNT_TIME ^d	1	0	0	1	0	0	1	1
AM ^e	1	1	0	1	1	0	0	0

^a Possible combinations of 3 covariates given defined time periods.

^b Two combinations that were not possible and excluded because a location recorded during HUNT_TIME must also be during AM, based on defined time periods.

^c 4 December 2010–30 January 2011 and 5–6 February 2011 in winter 2010–2011, and 3 December 2011–29 January 2012 and 4–5 February 2012 in winter 2011–2012.

^d 30 minutes before sunrise until sunset.

^e 30 minutes before sunrise until 30 minutes after sunset.

Table 2.3 Results from mixed effects logistic regression model showing differences in habitat selection of American black ducks (*Anas rubripes*) between years.

Parameter	Estimate	SE	Z
Intercept ^b	-8.79	0.11	-80.20
Dist_Road	-0.20	0.02	-10.10
Refuge	4.43	0.06	78.44
Cultivated	-0.41	0.11	-3.78
Emergent	2.42	0.07	37.16
Forested	-0.32	0.09	-3.42
Year ^c	0.12	0.14	0.83 ^a
Cultivated : Year	1.74	0.12	14.03
Emergent : Year	0.51	0.09	5.67
Forested : Year	1.34	0.12	11.54

^a All Z values significant ($P < 0.001$) except year effect ($P = 0.41$).

^b Model includes a random intercept for individuals.

^c Winters 2010–2011, 2011–2012.

Table 2.4 Diel habitat use comparison between mean percent of locations (standard deviation) for mortalities and surviving American black ducks (*Anas rubripes*) in western Tennessee, winters 2010–2012.

	Survivors ^a			Mortalities ^b				
	Forested ^c	Open water	Emergent	Cultivated	Forested	Open water	Emergent	Cultivated
Diurnal ^d	19.9 (17.4)	37.5 (21.8)	26.5 (21.6)	16.0 (16.7)	8.9 (12.6)	35.2 (34.1)	44.2 (39.9)	11.7 (28.7)
Nocturnal ^e	10.3 (14.8)	17.6 (15.3)	58.9 (22.8)	13.3 (19.8)	2.7 (5.1)	23.1 (29.7)	61.7 (35.5)	12.5 (28.6)

^a 99 individuals for diurnal and nocturnal habitat use.

^b 12 individuals for diurnal and nocturnal habitat use.

^c Refer to Table 2.1 for descriptions of habitats (Forested wetlands, Open water, Emergent/scrub-shrub wetlands, and Cultivated lands).

^d 30 minutes before sunrise until 30 minutes after sunset.

^e 31 minutes after sunset until 29 minutes before sunrise.

Table 2.5 Candidate set of 12 a priori mixed effects models used to investigate habitat selection of radiomarked female American black ducks (*Anas rubripes*) in Tennessee, winter 2010–2011.

Model description ^a	K^b	logLik ^c	AIC ^d	ΔAIC	w_i^e
Dist_Road ^f + Refuge ^g + Habitat ^h * Hunt_Time ⁱ * Hunt_Season ^k	19	-5,427.8	10,893.6	0	0.99
Dist_Road + Refuge + Habitat * AM ^j	11	-5,443.2	10,908.3	14.7	< 0.01
Habitat + Refuge + Dist_Road * AM	9	-5,545.0	11,090.0	196.4	< 0.01
Dist_Road + Habitat + Refuge * AM	9	-5,543.3	11,104.6	211	< 0.01
Dist_Road + Refuge + Habitat * Hunt_Season	11	-5,615.2	11,252.5	358.9	< 0.01
Dist_Road + Habitat + Refuge * Hunt_Season	9	-5,620.6	11,259.2	365.6	< 0.01
Dist_Road + Habitat * Refuge	10	-5,621.1	11,262.2	368.6	< 0.01
Dist_Road + Habitat + Refuge	7	-5,638.4	11,290.8	397.2	< 0.01
Habitat + Dist_Road * Refuge	8	-5,638.0	11,292.0	398.4	< 0.01
Habitat + Refuge	6	-5,656.5	11,325.0	431.4	< 0.01
Habitat	5	-7,819.7	15,649.5	4,755.9	< 0.01
Intercept only	2	-9,764.4	19,532.8	8,639.2	< 0.01

^a Models without locations in all categories (DIST_ROAD + REFUGE * HABITAT * AM and DIST_ROAD + HABITAT + REFUGE * HUNT_TIME * HUNT_SEASON) did not converge and are excluded from this table. A random intercept for individuals ($n = 62$) was included in all models.

^b n parameters.

^c Model negative log-likelihood.

^d Akaike's Information Criterion.

^e Relative likelihood of model (i) based on AIC value.

^f Standardized continuous variable for distance to nearest road (m).

^g Categorical variable with values of 1 = Tennessee National Wildlife Refuge and 0 = elsewhere.

^h Categorical variable indicating whether a location is within open water, emergent wetlands, forested wetlands, or cultivated habitats.

ⁱ Categorical variable with values of 1 = diurnal and 0 = nocturnal.

^j Categorical variable with values of 1 = during legal shooting hours and 0 = otherwise.

^k Categorical variable with values of 1 = during waterfowl hunting season and 0 = otherwise.

Table 2.6 Candidate set of 14 a priori mixed effects models used to investigate habitat selection of radiomarked female American black ducks (*Anas rubripes*) in Tennessee, winter 2011–2012.

Model description ^a	K^a	logLik ^b	AIC ^c	ΔAIC	w_i^d
Dist_Road ^e + Habitat ^g * Refuge ^f * AM ^h	18	-9,465.0	18,966.1	0	1.00
Dist_Road + Refuge + Habitat * Hunt_Time ⁱ * Hunt_Season ^j	19	-9,630.9	19,299.7	333.6	< 0.01
Dist_Road + Refuge + Habitat * AM	11	-9,660.4	19,342.7	376.6	< 0.01
Dist_Road + Habitat + Refuge * Hunt_Season * Hunt_Time	13	-9,698.6	19,423.2	457.1	< 0.01
Dist_Road + Habitat + Refuge * AM	9	-9,805.1	19,628.2	662	< 0.01
Habitat + Refuge + Dist_Road * AM	9	-9,842.4	19,702.7	736.6	< 0.01
Dist_Road + Habitat + Refuge * Hunt_Season	9	-9,865.1	19,748.2	782.1	< 0.01
Dist_Road + Habitat * Refuge	10	-9,907.5	19,834.9	868.8	< 0.01
Dist_Road + Refuge + Habitat * Hunt_Season	11	-9,935.4	19,892.9	926.8	< 0.01
Habitat + Dist_Road * Refuge	8	-9,987.8	19,991.5	1,025.4	< 0.01
Dist_Road + Habitat + Refuge	7	-10,020.8	20,055.5	1,089.4	< 0.01
Habitat + Refuge	6	-10,057.4	20,126.9	1,160.8	< 0.01
Habitat	5	-13,046.0	26,102.1	7,136	< 0.01
Intercept only	2	-15,137.5	30,279.1	11,312.9	< 0.01

^a A random intercept for individuals ($n = 49$) was included in all models.

^b n parameters.

^c Model log-likelihood.

^d Akaike's Information Criterion.

^e Relative likelihood of model (i) based on AIC value.

^f Standardized continuous variable for distance to nearest road (m).

^g Categorical variable with values of 1 = Tennessee National Wildlife Refuge and 0 = elsewhere.

^h Categorical variable indicating whether a location is within open water, emergent wetlands, forested wetlands, or cultivated habitats.

ⁱ Categorical variable with values of 1 = diurnal and 0 = nocturnal.

^j Categorical variable with values of 1 = during legal shooting hours and 0 = otherwise.

^k Categorical variable with values of 1 = during waterfowl hunting season and 0 = otherwise.

Table 2.7 Area of available habitat for radiomarked American black ducks (*Anas rubripes*) within the study area.

Habitat ^a	On TNWR ^b	Off TNWR
Open water	8,110.53	16,717.59
Forested wetland	2,339.82	19,439.19
Cultivated land	1,801.17	66,480.21
Emergent/scrub-shrub wetland	685.29	1,593.18

^a Area (ha) of habitat types determined by supervised classification of Landsat-5 Thematic Mapper imagery.

^b Tennessee National Wildlife Refuge.

Table 2.8 Summary of best supported mixed effects logistic regression model used to predict habitat selection for American black ducks (*Anas rubripes*) in western Tennessee, winter 2010–2011.

Parameter ^a	Mean Estimate ^b	SD	95% Credible Interval
Intercept	-11.176	0.241	-11.643, -10.713
Cultivated	-0.998	0.394	-1.835, -0.272
Emergent	3.659	0.144	3.383, 3.945
Forested	-0.119	0.234	-0.596, 0.319
Refuge	6.009	0.188	5.652, 6.375
Dist_Road	-0.216	0.0311	-0.278, -0.156
Hunt_Season	0.498	0.158	0.191, 0.806
Hunt_Time	1.484	0.151	1.190, 1.785
Hunt_Time : Hunt_Season	-0.533	0.2004	-0.924, -0.149
Cultivated : Hunt_Season	1.488	0.433	0.687, 2.372
Emergent : Hunt_Season	-0.936	0.193	-1.31, -0.403
Forested : Hunt_Season	-1.166	0.384	-1.929, -0.403
Cultivated : Hunt_Time	1.185	0.439	0.360, 2.089
Emergent : Hunt_Time	-1.993	0.189	-2.365, -1.627
Forested : Hunt_Time	0.207	0.280	-0.333, 0.778
Cultivated : Hunt_Time : Hunt_Season	-1.812	0.536	-2.851, -0.795
Emergent : Hunt_Time : Hunt_Season	0.333	0.278	-0.212, 0.870
Forested : Hunt_Time : Hunt_Season	0.836	0.449	-0.0391, 1.727
σ (Individual Random Effect)	0.660	0.0787	0.521, 0.828

^a Parameters from REFUGE + DIST_ROAD + HABITAT * HUNT_TIME * HUNT_SEASON.

^b Mean estimates from Bayesian analysis of 3 chains with 130,000 iterations each and a burn-in of 30,000 and thinning rate of 20.

Table 2.9 Summary of best supported mixed effects logistic regression model used to predict habitat selection for American black ducks (*Anas rubripes*) in Tennessee, winter 2011–2012.

Parameter ^a	Mean Estimate ^b	SD	95% Credible Interval
Intercept	-7.646	0.290	-8.238, -7.120
Dist_Road	-0.284	0.027	-0.338, -0.232
Cultivated	-0.502	0.330	-1.164, 0.131
Emergent	3.160	0.320	2.572, 3.799
Forested	1.046	0.310	0.471, 1.664
Refuge	2.935	0.296	2.411, 3.524
AM	-0.104	0.331	-0.716, 0.562
Cultivated : Refuge	3.433	0.356	2.735, 4.131
Emergent : Refuge	1.237	0.346	0.551, 1.874
Forested : Refuge	0.479	0.342	-0.195, 1.115
Cultivated : AM	0.717	0.376	-0.070, 1.426
Emergent : AM	-0.978	0.428	-1.848, -0.165
Forested : AM	0.144	0.384	-0.593, 0.865
Refuge : AM	0.724	0.354	0.015, 1.381
Cultivated : Refuge : AM	-3.004	0.413	-3.794, -2.151
Emergent : Refuge : AM	-1.719	0.455	-2.582, -0.800
Forested : Refuge : AM	-1.231	0.418	-2.028, -0.423
σ (Individual Random Effect)	0.658	0.077	0.525, 0.826

^a Parameters from DIST_ROAD + HABITAT * REFUGE * AM.

^b Mean estimates from Bayesian analysis of 3 chains with 42,000 iterations each and a burn-in of 2,000 and thinning rate of 10.

Table 2.10 Odds of selection of habitats for American black ducks (*Anas rubripes*) on Tennessee National Wildlife Refuge during winter 2010–2011 in relation to hunting season and legal hunting hours.

Habitat	Hunting Season		Post-Hunting Season	
	Legal	Post-Legal	Legal	Post-Legal
Cultivated land	0.022 ^{a,b} (0.013, 0.032)	0.016 (0.011, 0.022)	0.031 (0.021, 0.043)	0.0023 (0.00094, 0.0041)
Open water	0.024 (0.019, 0.031)	0.0095 (0.0072, 0.012)	0.025 (0.019, 0.032)	0.0058 (0.0042, 0.0077)
Forested wetland	0.019 (0.013, 0.027)	0.0027 (0.0014, 0.0045)	0.028 (0.0201, 0.037)	0.0052 (0.0032, 0.0076)
Emergent/scrub-shrub wetland	0.071 (0.051, 0.095)	0.14 (0.11, 0.18)	0.13 (0.104, 0.17)	0.22 (0.18, 0.27)

^a Mean (95% credible interval) calculated as derived parameters in the Bayesian model, REFUGE + DIST_ROAD + HABITAT * HUNT_SEASON * HUNT_TIME.

^b For the average distance to the nearest road (361 m).

Table 2.11 Odds of selection of habitats for American black ducks (*Anas rubripes*) during winter 2011–2012 during diurnal and nocturnal periods.

Habitat	TNWR ^a			Off TNWR		
	AM	PM	AM	AM	PM	PM
Cultivated land	0.032 ^{b,c} (0.024, 0.041)	0.17 (0.13, 0.21)	0.00054 (0.00042, 0.00068)	0.00054 (0.00042, 0.00068)	0.00029 (0.0002, 0.00041)	0.00029 (0.0002, 0.00041)
Open water	0.017 (0.013, 0.021)	0.0091 (0.0067, 0.012)	0.00044 (0.00028, 0.00065)	0.00044 (0.00028, 0.00065)	0.0005 (0.00026, 0.00081)	0.0005 (0.00026, 0.00081)
Forested wetland	0.026 (0.021, 0.033)	0.042 (0.032, 0.053)	0.0014 (0.0011, 0.0019)	0.0014 (0.0011, 0.0019)	0.0014 (0.00096, 0.0019)	0.0014 (0.00096, 0.0019)
Emergent/scrub-shrub wetland	0.092 (0.073, 0.12)	0.73 (0.59, 0.9)	0.0039 (0.0024, 0.0058)	0.0039 (0.0024, 0.0058)	0.011 (0.0077, 0.016)	0.011 (0.0077, 0.016)

^a Tennessee National Wildlife Refuge.

^b Mean (95% credible interval) calculated as derived parameters in the Bayesian model, DIST_ROAD + HABITAT * REFUGE * AM.

^c For the average distance to the nearest road (361 m).

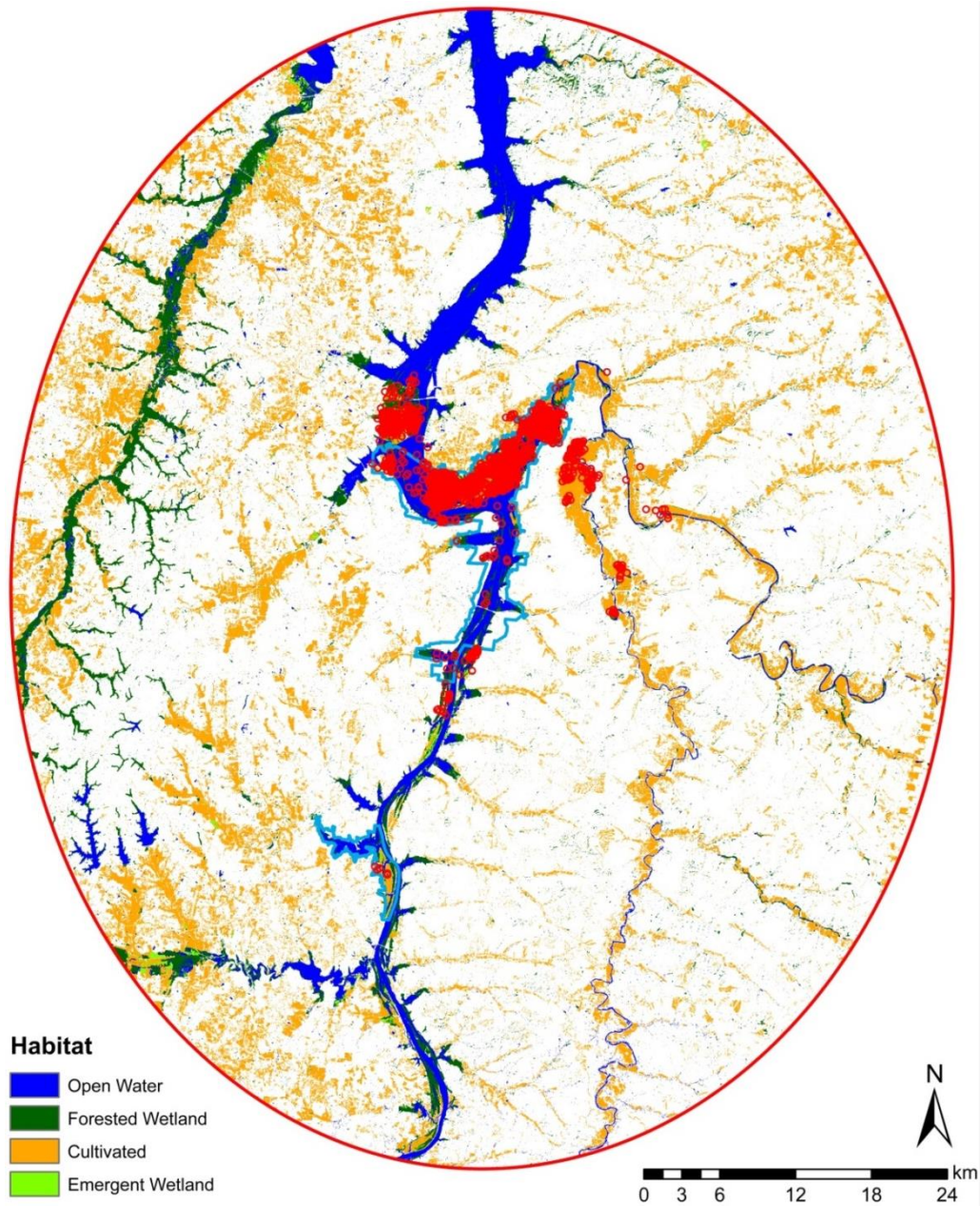


Figure 2.1 Map of study area during winters 2010–2012.

Tennessee National Wildlife Refuge is outlined in light blue, and locations of radiomarked female American black ducks (*Anas rubripes*) are red points. Available habitats are open water in dark blue, forested wetlands in dark green, cultivated lands in orange, and emergent/scrub-shrub wetlands in light green.

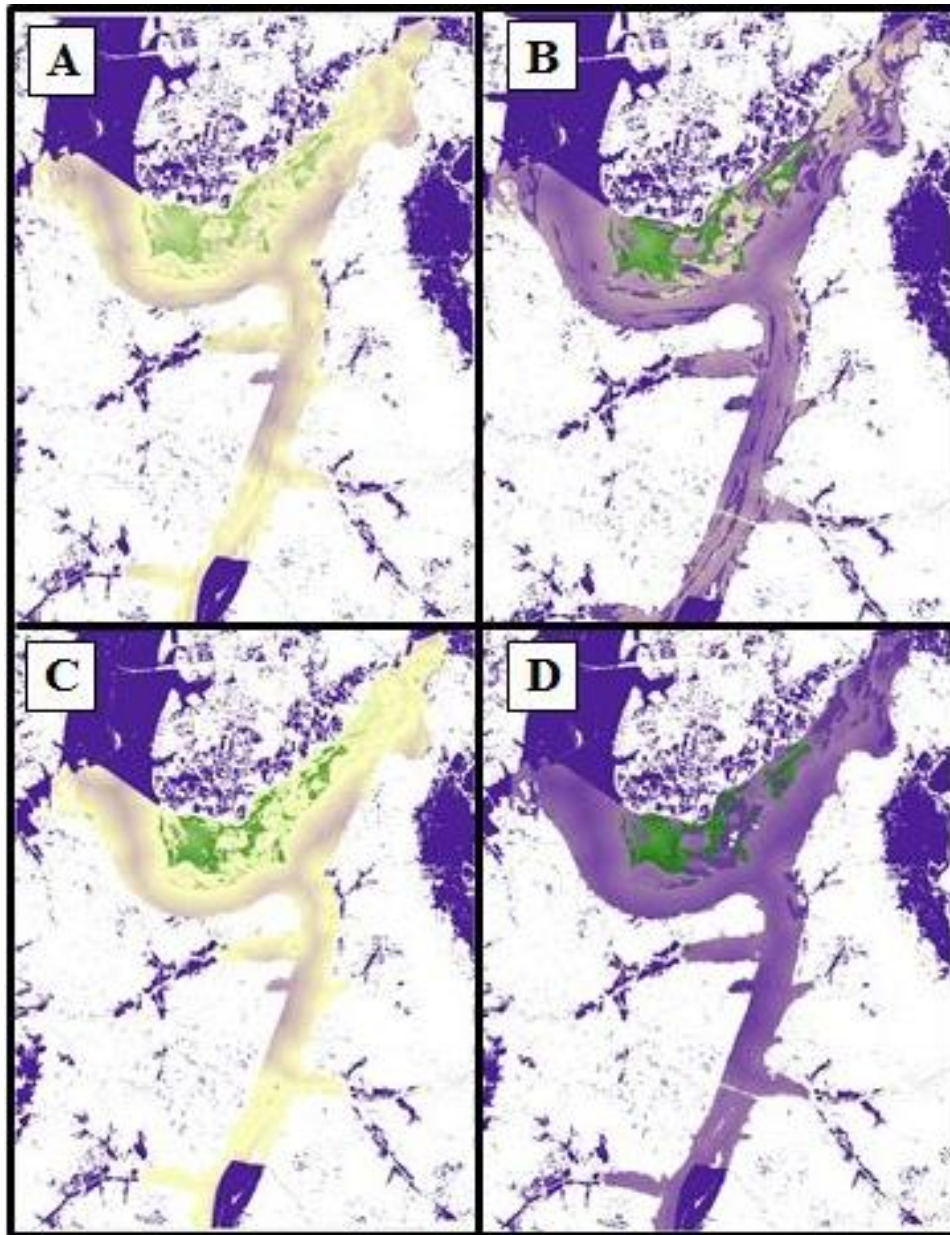


Figure 2.2 Probability of habitat use of Duck River Unit of Tennessee National Wildlife Refuge by American black ducks (*Anas rubripes*) in winter 2010–2011.

Probability values during hunting season and legal shooting hours (A), hunting season and after shooting hours (B), post-hunting season and within legal shooting hours (C), and post-hunting season and after shooting hours (D) increase moving from purple to green colors.

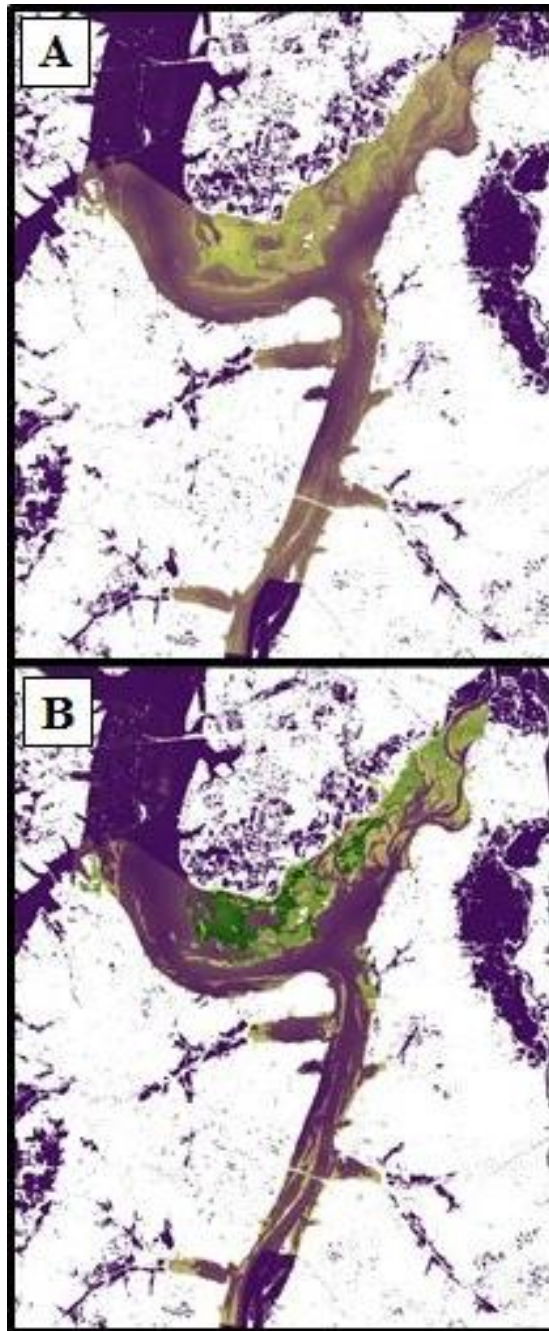


Figure 2.3 Probability of habitat use of Duck River Unit of Tennessee National Wildlife Refuge by American black ducks (*Anas rubripes*) in winter 2011–2012.

Probability values during diurnal (A) and nocturnal (B) hours increase moving from purple to green colors.

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APPENDIX A

COMPLETE MODEL SET FROM KNOWN-FATE SURVIVAL ANALYSIS

Table A.1 Model set for first step of model selection for survival analysis of radiomarked American black ducks (*Anas rubripes*).

Model description	K^a	AIC_c^b	ΔAIC_c	w_i^c	Dev ^d
Year ^e * Mass ^f	4	140.62	0.00	0.360	132.60
Mass	2	142.64	2.02	0.131	138.64
Constant ^g	1	142.88	2.26	0.117	54.38
Age	2	143.80	3.18	0.074	53.29
Age + Mass	3	144.01	3.39	0.066	137.99
Year + Mass	3	144.04	3.41	0.066	138.02
Year	2	144.42	3.80	0.054	53.91
Age * Mass	4	145.34	4.72	0.034	137.32
Year + Age	3	145.49	4.86	0.032	52.97
Year + Age + Mass	4	145.57	4.94	0.030	137.54
Year	8	146.23	5.61	0.022	130.14
Year * Age	4	147.01	6.39	0.015	52.48

^a n parameters.

^b Akaike's Information Criteria for small sample sizes.

^c Relative likelihood of model (i) based on AIC_c value.

^d Model deviance.

^e Winters 2010–2011, 2011–2012.

^f Residual values from the best regression model of body mass of female black ducks at capture on date of capture.

^g Hatch year/second year (HY) or after hatch year/after second year (AHY).

Table A.2 Model set for second step of model selection for survival analysis of radiomarked American black ducks (*Anas rubripes*).

Model description	K^a	AIC_c^b	ΔAIC_c	w_i^c	Dev
Year * Mass	4	140.62	0.00	0.364	132.60
Year * Mass + Hunt	5	142.61	1.98	0.135	132.57
Mass	2	142.64	2.02	0.133	138.64
Hunt * Mass	4	142.76	2.14	0.125	134.74
Constant	1	142.88	2.26	0.118	54.38
Mass + Hunt	3	144.55	3.93	0.051	138.54
Hunt	2	144.79	4.17	0.045	54.28
Hunt * Age	4	145.63	5.01	0.030	51.10

^a n parameters.

^b Akaike's Information Criteria for small sample sizes.

^c Relative likelihood of model (i) based on AIC_c value.

^d Model deviance.

^e Winters 2010–2011, 2011–2012.

^f Residual values from the best regression model of body mass of female black ducks at capture on date of capture.

^g Dummy variable for each day coded as 0 = not hunted and 1 = hunted.

^h Hatch year/second year (HY) or after hatch year/after second year (AHY).

Table A.3 Model set for final step of model selection for survival analysis radiomarked American black ducks (*Anas rubripes*).

Model description	K^a	AIC_c^b	ΔAIC_c	w_i^c	Dev^d
Year ^e * Mass ^f	4	140.62	0.00	0.138	132.60
Year * Mass + PRCP ^g	5	141.78	1.15	0.077	131.74
Year * Mass + WSI ^h	5	142.37	1.75	0.057	132.33
Year * Mass + TMIN ⁱ	5	142.49	1.87	0.054	132.45
Year * Mass + SNOW ^j	5	142.62	2.00	0.051	132.58
Mass	2	142.64	2.02	0.050	138.64
HUNT * Mass	4	142.76	2.14	0.047	134.74
Constant ^k	1	142.88	2.26	0.044	54.38
HUNT * Mass + PRCP	5	143.63	3.00	0.031	133.59
Year * Mass + PRCP + WSI	6	143.75	3.13	0.029	131.70
Year * Mass + PRCP + SNOW	6	143.78	3.16	0.028	131.73
PRCP + Mass	3	143.79	3.16	0.028	137.77
Year * Mass + TMIN + PRCP	6	143.79	3.16	0.028	131.73
PRCP	2	143.96	3.34	0.026	53.45
SNOW + Mass	3	144.50	3.88	0.020	138.49
SNOW * Mass	4	144.61	3.99	0.019	136.58
HUNT * Mass + SNOW	5	144.64	4.02	0.018	134.60
WSI + Mass	3	144.65	4.02	0.018	138.63
TMIN + Mass	3	144.65	4.02	0.018	138.63
HUNT * Mass + WSI	5	144.72	4.09	0.018	134.68
HUNT * Mass + TMIN	5	144.73	4.10	0.018	134.69
SNOW	2	144.79	4.17	0.017	54.28
WSI	2	144.87	4.24	0.016	54.36
TMIN	2	144.87	4.25	0.016	54.36
HUNT * Mass + PRCP + SNOW	6	145.55	4.92	0.012	133.49
HUNT * Mass + TMIN + PRCP	6	145.63	5.01	0.011	133.58
HUNT * Mass + PRCP + WSI	6	145.64	5.02	0.011	133.59
Year * Mass * PRCP	8	145.64	5.02	0.011	129.55
PRCP * Mass	4	145.70	5.07	0.011	137.67
PRCP + SNOW	3	145.90	5.27	0.010	53.38
TMIN + PRCP	3	145.94	5.31	0.010	53.42
WSI + PRCP	3	145.95	5.33	0.010	53.43
WSI * Mass	4	146.39	5.77	0.008	138.37
TMIN * Mass	4	146.54	5.92	0.007	138.51
Year * Mass * WSI	8	147.01	6.38	0.006	130.91
PRCP * SNOW	4	147.73	7.11	0.004	53.21
Year * Mass * TMIN	8	147.74	7.11	0.004	131.64
WSI * PRCP	4	147.80	7.18	0.004	53.27

Table A.3 (Continued)

TMIN * PRCP	4	147.90	7.28	0.004	53.37
Year * Mass * SNOW	8	148.40	7.78	0.003	132.31
PRCP * HUNT * Mass	8	148.49	7.87	0.003	132.40
SNOW * HUNT * Mass	8	148.61	7.98	0.003	132.51
WSI * HUNT * Mass	8	149.62	9.00	0.002	133.53

^a n parameters.

^b Akaike's Information Criteria for small sample sizes.

^c Relative likelihood of model (i) based on AIC_c value.

^d Model deviance.

^e Winters 2010–2011, 2011–2012.

^f Residual values from the best regression model of body mass of female black ducks at capture on date of capture.

^g Average precipitation value (mm) over 3-day interval.

^h Average weather severity index value over 3-day interval; developed by Schummer et al. (2010), which incorporates mean daily temperature, snowfall, and snow depth into a single index value.

ⁱ Average minimum temperature (°C) over 3-day interval.

^j Average snowfall value (mm) over 3-day interval.