Survival, habitat use, and spatiotemporal use of wildlife management areas by female mallards in Mississippi's Alluvial Valley

By

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2013

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The Mississippi Alluvial Valley (MAV) is an important region for wintering mallards (*Anas platyrhynchos*) in North America, yet little is known about their spatiotemporal habitat use and related survival in Mississippi. I tracked 126 radio-marked female mallards to quantify survival, habitat use, and use of wildlife management areas (WMAs) with experimental hunt regimes in the south MAV of Mississippi during winters 2010-2012. Daily survival was greatest in agricultural (0.997) and moist-soil (0.999) habitats in winters 2010-2011 and 2011-2012, respectively. Overall interval survival across both winters was 0.60 (SE = 0.02). Forested (40-54%) and moist-soil wetlands (41-59%) received greatest use diurnally and nocturnally, respectively. Mallards used WMAs similarly ($P > 0.22$) whether they were hunted 2- or 4-days/week. My data suggest that complexes of flooded cropland, forest, and moist-soil habitats are suitable habitats for mallards in the MAV, WMAs can be hunted 4-days/week, and sanctuaries should be revised at two WMAs.

DEDICATION

My work and thesis are dedicated to my late brother, Brian Jay Lancaster.

A stone's cast from where each of our first ducks fell is a tree. Scribed in its periderm, with the key of your RX-7, are our names and the year of an uneventful squirrel hunt we shared years later. I have yet to find that tree, despite searching each time I pass to pursue the wood ducks we once hunted together.

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CHAPTER I

WINTER SURVIVAL OF FEMALE MALLARDS IN MISSISSIPPI'S ALLUVIAL VALLEY

The mallard (*Anas platyrhynchos*) is an abundant and ecologically and economically important species of waterfowl in Mississippi and throughout the northern hemisphere (Bellrose 1976, Baldassarre and Bolen 2006, U.S. Fish and Wildlife Service 2013, Grado et al. 2011). The Mississippi Flyway forms the primary migratory corridor for midcontinent Nearctic mallards, especially for those wintering in the lower Mississippi Alluvial Valley (MAV; Bellrose 1968, Bellrose 1976). The MAV is an important region for non-breeding mallards in the United States, as > 40% of mallards in the flyway use this region during autumn and spring migration and winter (Bellrose 1976, Nichols et al. 1983, Davis et al. 2011, Pearse et al. 2012). Mallards and other waterfowl rely on the MAV's bottomland hardwood forests, other extant and managed wetlands (e.g., moist-soil areas), and flooded croplands to satisfy their physiological and behavioral needs during the non-breeding period (Reinecke et al. 1989, Heitmeyer 2006, Pearse et al. 2012).

Historically, bottomland hardwood forests and other wetlands inundated by natural riverine flooding and landscape run-off provided foraging and other habitats for mallards. Amid great loss of bottomland hardwoods in the MAV (Mitsch and Gosselink 2007:383), deliberate and natural flooding of hardwood bottomlands, croplands, and

restored wetlands (e.g., Wetland Reserve Program [WRP]) remains critical to meeting needs of wintering mallards (Reinecke et al. 1989, Dabbert and Martin 2000, Heitmeyer 2006, J. M. Tirpak, LMVJV, unpublished report). Mallards are adept at exploiting food resources, often moving among habitats to ingest agricultural and natural seeds and tubers (Wright 1959, Delnicki and Reinecke 1986, Combs and Fredrickson 1996, Dabbert and Martin 2000, Davis and Afton 2010, Callicutt et al. 2011). Although the general significance of the MAV to wintering mallards is understood (Nichols et al. 1983, Reinecke et al. 1989, Heitmeyer et al. 2006), few studies have addressed use of specific complexes of habitats by mallards (Davis et al. 2009, Pearse et al. 2012) and their influence on the birds' survival during winter (Reinecke et al. 1987, Dugger et al. 1994, Davis et al. 2011). Considering the importance of the MAV to North American mallard populations and continuing natural and agricultural dynamics in the MAV, increased contemporary knowledge of mallard winter survival related to environmental influences is needed.

Mallard population dynamics are strongly influenced by events that occur during the breeding season, such as nest success and duckling survival (Hoekman et al. 2002, Amundson and Arnold 2011). Hunter harvest is the primary cause of mortality for male mallards annually and female mallards during the non-breeding season (Reinecke et al. 1987, Hoekman et al. 2002, Fleskes et al. 2007, Link 2007). However, mortality of female mallards during the non-breeding season may only account for 9% of the variation in annual population growth (Hoekman et al. 2002). Hoekman et al. (2002) used a survival rate of 80% for wintering mallards, but recent work suggested that winter survival may be less in the MAV and other winter regions (i.e., 54-84%; Kirby and

Cowardin 1986, Reinecke et al. 1987, Bergan and Smith 1993, Fleskes et al. 2007, Davis et al. 2011). Thus, the influence of winter survival on annual population growth of mallards may be underestimated (Hoekman et al. 2002, Davis et al. 2011).

Previous radio-telemetry and reward-band studies identified hunter harvest as a primary cause of mortality for female mallards outside the breeding season (Blohm et al. 1987, Reinecke et al. 1987, Hoekman et al. 2002, Fleskes et al. 2007, Link 2007). Therefore, understanding survival in relation to hunting and non-hunting periods helps scientists and managers identify possible influences of hunting-related disturbances and impacts on mallard population dynamics (Davis et al. 2011). Dugger et al. (1994) detected no mortalities of radio-marked mallards following hunting season in Arkansas, whereas Davis et al. (2011) observed increased mallard mortality during the hunting season in Louisiana and Arkansas. Despite greater mortality during hunting season, cause-specific mortality rates were greater for non-hunting sources including predation and unknown causes (Davis et al. 2011). Reinecke et al. (1987) also reported decreased survival during hunting season, although hunting was the principal source of mortality. Therefore, mallards are likely susceptible to varied causes of mortality during waterfowl hunting seasons.

Survival of wintering mallards also can be influenced by individuals' body mass, year effects, and individuals' age (Reinecke et al. 1987, Bergan and Smith 1993, Jeske et al. 1994, Fleskes et al. 2007, Link 2007, Davis et al. 2011). Generally, adult mallards survive greater than juveniles (Reinecke et al. 1987), and survival is correlated positively with body condition at capture (Bergan and Smith 1993, Link 2007, Davis et al. 2011). Davis et al. (2011) reasoned that female mallards using forested wetlands may have

energetic and survival advantages, because females were less likely to switch habitats and moved shorter distances than females in other habitats, and dense understory may have reduced avian predation (Davis and Afton 2010). These results are consistent with knowledge that hardwood bottomlands were ancestral wintering habitats for mid-content mallards and provided the species with plant and animal foods and other resources (Heitmeyer et al. 2005). Indeed, factors influencing mallard survival currently during winter are complex and likely depend on several inter-related factors, such as body condition, disturbance, habitat quality and availability, hydrology, winter temperatures, or other endogenous or exogenous factors (Nichols et al. 1983, Dooley et al. 2010, Schummer et al. 2010, Davis et al. 2011).

Only one previous study has quantified survival of mallards in the MAV in Mississippi (Reinecke et al. 1987). This study provided an important point of reference and opportunity for comparison of data from the 1980s and the present. Additionally, Davis et al. (2011) studied winter ecology of mallards in northeastern Louisiana and southeastern Arkansas, thus providing contemporary estimates of survival from adjacent locales in the MAV. Although contemporary research of satellite marked mallards signifies diminutive philopatry to winter locations (Krementz et al. 2012), studies have revealed apparent affinities by female mallards to specific areas after arrival to the MAV. For example, Davis et al. (2009) witnessed relatively little movement of radio-marked individuals across the Mississippi River between western (Arkansas and Louisiana) and eastern (Mississippi) portions of the MAV. This behavior suggests existence of different localized cohorts or possibly subpopulations of mallards in the MAV, or partly consequential of effects of radio-transmitters. Thus, further study of these mallards is

warranted, because they may encounter different selective pressures associated with different complexes of habitats and differential hunting disturbance and mortality. However, for my study, I must presuppose that radio-marking did not measurably affect the birds. Moreover, radio-marking and telemetry are the only electronic field technology presently available for collection of daily survival data.

Landscape composition in western and eastern portions of the MAV is noticeably different. Seven-13 times more rice was grown in Louisiana and Arkansas than Mississippi during my study (United States Department of Agriculture [USDA] National Agricultural Statistics Service 2013). Additionally, forested wetlands dominated Davis' et al. (2011) study area (66% forested: 16% agriculture), but mine was 38% forested and 41% agriculture (USDA Nat. Ag. Stats. Service 2013). Understanding mallard survival strategies within different landscapes will help identify "suitable" habitats (sensu Fretwell 1972) and guide habitat conservation planning and implementation by the Lower Mississippi Valley Joint Venture (LMVJV) of the North American Waterfowl Management Plan (NAWMP; NAWMP 2012).

Currently, the LMVJV uses bio-energetic models to calculate habitat requirements to support population goals of wintering waterfowl (Reinecke et al. 1989, Reinecke and Loesch 1996, Miller and Newton 1999). Although such models have been successful and widely used by Joint Ventures across the country (Loesch et al. 1995, Central Valley Joint Venture 2006), the NAWMP Assessment Team and other researchers recognize need to develop a link between habitat conditions and key waterfowl vital rates, including survival and recruitment (Davis et al. 2011, J. M. Tirpak, LMVJV, unpublished report). Kaminski et al. (1985) suggested future priorities for

waterfowl research should include determining whether and how habitat selection during non-breeding periods influences survival and subsequent reproductive success. J. M. Tirpak (LMVJV, unpublished report) re-emphasized this need and discussed strategies for obtaining large-scale estimates of waterfowl survival and habitat use. J. M. Tirpak (LMVJV, unpublished report) proposed use of leg-banding, nasal saddles, very high frequency (VHF) telemetry, and satellite platform transmitter terminals (PTTs) to acquire these data. Despite inherent strengths and limitations of these techniques, VHF telemetry is relatively economical and a reliable technique to generate appropriate data from populations in desired geographic areas, as evidenced by its wide use in waterfowl survival studies (Reinecke 1987, Conroy et al. 1989, Dugger et al. 1994, Moon and Haukos 2006, Fleskes et al. 2007, Link 2007, Davis et al. 2007, Davis et al. 2011).

Use of VHF telemetry, coupled with modern statistical and computational technology, increasingly enables understanding and estimation of habitat-related survival of waterfowl (Barker et al. 2005). The multistate model in Program MARK allows individuals (e.g., mallards) to occur in multiple strata (e.g., habitats) through the study period each of which may have an independent survival probability (White and Burnham 1999, White et al. 2006). For example, in a study of adult songbirds in Newfoundland, Canada, Whitaker et al. (2008) found evidence for habitat specific survival of ruby-crowned kinglets (*Regulus calendula*) and yellow-rumped warblers (*Dendroica coronata*), reporting that survival for each species was least in landscapes that contained clear-cut forests.

These technological and analytical advancements allowed me to quantify survival of female mallards that used a complex of wetland habitats in the Mississippi MAV

(Pearse et al. 2012). Despite numerous studies that have examined effects of winter, season, and indexes of body condition on mallard survival, no study has attempted to link winter survival to specific habitats. Therefore, my objectives were to test for possible correlates of daily habitat use, winter of study, within-winter period, female age, and body condition at capture on daily survival rates of radio-marked female mallards in the Mississippi MAV. I developed a set of *a priori* models incorporating planned combinations of aforementioned explanatory variables to evaluate which combinations of variables best explained daily survival rates of female mallards in Mississippi.

Study Area

I captured mallards at three state-managed Wildlife Management Areas (WMAs) in the southern portion of the MAV in Mississippi: 1) Howard Miller WMA is a 971 ha seasonally flooded complex near Rolling Fork, Mississippi (32°49’48.93” N, 90°58’51.61” W), which is annually planted to rice and soybean but also contains seasonal emergent vegetation supplemented with plantings of corn and Japanese millet; 2) Mahannah WMA, near Vicksburg, Mississippi (32°32’54.95” N, 90°52’14.08” W), is a 5,100 ha complex with expansive bottomland hardwoods, scrub-shrub, seasonal emergent vegetation, and rice and soybean. Approximately 80% of Mahannah WMA is seasonally and naturally flooded annually, and the remaining area is managed for upland species, primarily white-tailed deer (*Odocoileus virginianus*); and 3) Muscadine Farms WMA, near Avon, Mississippi (33°13’29.32” N, 90°59’01.51” W), is a 607 ha retired catfish pond complex owned by the U.S Army Corps of Engineers. The complex is managed for waterfowl through seasonal vegetation manipulation, supplemental

plantings of corn and Japanese millet, and strategic fall-winter flooding of impoundments.

I tracked female mallards in all areas within 80 km of trapping sites, which included portions of northeast Louisiana and southeast Arkansas (Figure 1.1; Cox and Afton 1997, Davis et al. 2009). In addition to trapping locations, the tracking area included publicly owned (Mississippi Department of Wildlife, Fisheries, and Parks [MDWFP]) and managed WMAs (i.e., Charlie Capps, Lake George, Leroy Percy, Shipland, Sky Lake, Stoneville, Sunflower, and Twin Oaks WMAs). State managed lands in the study area outside of Mississippi included Big Lake and Buckhorn WMAs in Louisiana and Casey Jones and Seven Devils Lake WMAs in Arkansas. Federal lands included Dahomey, Hillside, Holt Collier, Mathews Brake, Morgan Brake, Panther Swamp, Theodore Roosevelt, and Yazoo National Wildlife Refuges (NWR) in Mississippi, Delta National Forest in Mississippi, Handy Brake and Tensas River NWRs in Louisiana, and Overflow NWR in Arkansas. Additional environmental details of the MAV are in the literature (e.g., Reinecke et al. 1989, Baldassarre and Bolen 2006).

Methods

Mallard Capture and Tracking

I captured female mallards from early November 2010-2011 through late January 2011-2012 on WMAs using swim in traps modified from those described by Hunt and Dahlka (1953) or rocket nets fired from portable platforms (Dill and Thornberry 1950, Cox and Afton 1994). Capture sites were baited with rice, soybean, sweet potato, or corn and were located throughout the WMAs prior to hunting season. Ten to 12 days prior to hunting season, all traps and remaining bait in hunting units were removed. Traps were

relocated to sanctuaries as distantly as possible from waterfowl hunting areas to eliminate possible effects of bait on duck distribution and hunting.

I aged captured females as juvenile (hatch year; HY) or adult birds (after hatch year; AHY) according to wing plumage characteristics (Carney 1992). I banded each female with a United States Fish and Wildlife Service aluminum leg band and attached a 23 g VHF backpack transmitter (Dwyer 1972). Transmitters had a pulse of 55 beats per minute, a life expectancy of 150 days, and a mercury type mortality sensor that doubled the pulse rate when transmitters were motionless for ≥8 hours. Transmitters weighed 2.1% (± 0.02% [SE], n = 113) of mean female body mass on date of capture. Transmitter weight < 5% of a bird's body mass are thought to prevent physiological or behavioral burden on the individual (Cochran 1980, Casper 2009). I measured flattened wing chord (± 1 mm), tarsus length (± 0.01 mm), and mass (± 5 g) of captured females to calculate a body condition index (Link 2007, Davis et al. 2011). I held females 4-6 hours after morning capture and 12-18 hours (overnight) when captured in the afternoon to allow adjustment to the transmitter and ensure proper fit (Davis et al. 2009). During acclimation periods, birds had access to corn and water ad libitum. I released instrumented females with captured conspecific males or females to minimize possible disruption of pair bonds (Cox and Afton 1998*a*). All capture, handling, and marking methods were approved by the Mississippi State University Institutional Animal Care and Use Committee protocol (# 10-070).

I tracked radio-marked females using trucks equipped with roof-mounted 4-element, null-peak antenna arrays, electronic compasses, Global Positioning System (GPS) units, and laptop computers with Location of a Signal software (LOAS 4.0;

Ecological Software Solutions LLC, Hegymagas, Hungary; Cox et al. 2002, Gilsdorf et al. 2007). I calibrated electronic compasses to known locations of beacon transmitters ± 0.5° and trained technicians by triangulating beacon transmitters until they could successfully maintain an azimuth standard deviation of ≤ 3º (Davis et al. 2009). I tracked radio-marked mallards diurnally (30 min before sunrise to 30 min after sunset) throughout the study area, defined as an area of 80 km radius from capture locations (Cox and Afton 1997, Davis et al. 2009). I chose a random radio-marked bird to begin tracking and a random direction so that individual locations were gathered at random intervals. When few females were available for tracking, I randomly chose a time of the day (i.e., morning, mid-day, afternoon) and corresponding nocturnal period to track females. Using a fixed wing aircraft equipped with left and right directional antennas, I pursued radio-marked mallards not detected from trucks after 2 consecutive days. The pilot flew at an altitude of 2,100-2,800 m and descended to 300 m elevation to pinpoint an individual (Gilmer et al. 1981). Upon locating a bird from the air, I recorded GPS coordinates along with distance and direction to a recognizable landmark and relayed information to technicians in telemetry trucks, so they could locate and triangulate birds' locations. I did not use aerially derived locations in data analyses, because accurate locations of birds were obtained from the ground on the same day following aerial location.

I attempted to record 3 azimuths to calculate each female location, but I continued to add azimuths until error ellipses fell within one habitat type or available vantage points were exhausted. Locations containing ≥ 3 azimuths comprised 96.5% of total locations, although, in some instances, road inaccessibility forced me to use bi-angulations (3.5% of

locations) from the best available vantage points. If multiple triangulations occurred for an individual in a day, I used the first location, unless the subsequent location contained more azimuths. The LOAS software estimated point locations for each bird with a maximum likelihood estimator (Lenth 1981) using a bearing standard deviation of 3° (Davis et al. 2009). I examined azimuths and point locations in real-time and immediately discarded apparently erroneous locations and re-triangulated the individual.

When a mortality signal was detected, I used a hand held antenna to approach the transmitter location and collect evidence on the cause of death. I categorized each mortality event either as hunting or non-hunting related using the female carcass, presence of predator tracks or other sign around the carcass, and marks on the transmitter as evidence on cause of death (Davis et al. 2011).

Statistical Analyses

I excluded the first three days of exposure following capture and release of radio-marked females from survival analysis to avoid any possible biases from stress induced by capture and handling (Cox and Afton 1998*a*). Thereafter, I transferred female locations into a geographic information system (GIS) in ARCMAP 9.3.1 (Environmental Systems Research Institute 2005). Within GIS, I assigned a habitat type to each location determined by visual inspection, contact with landowners/managers, or a combination of National Agricultural Imagery Program imagery and United States Department of Agriculture Service Agency records. I categorized daily locations into one of four strata based on occupied habitat types (Pearse et al. 2012): 1) [AG] flooded agricultural lands including rice, soybean, corn, grain sorghum, or other crops; 2) [S-EM] seasonal emergent wetlands, including wetlands dominated by natural herbaceous plants, managed

moist-soil wetlands, and agricultural fields left fallow after the previous growing season(s); 3) [FO] forested wetlands, including all wetlands dominated by trees and scrub-shrub habitat (Fredrickson et al. 2005, Pearse et al. 2012); and 4) [P-W] permanent water including all wetlands that hold water annually including aquaculture ponds, river channels, and oxbow lakes.

During my study, the MDWFP managed a 60-day duck hunting season beginning in late November and ending in late January, with a goal to maximize number of weekends available for hunting. Thus, multiple season splits (i.e., periods of hunting separated by periods of no hunting) were implemented during the hunting season. Similar to Davis et al. (2011), I divided winters into five time periods based on their timing relative to hunting season: 1) period before hunting season ([PRE] 16 - 25 November 2010 and 16 - 24 November 2011), 2) first two hunting periods ([HUNT1] 26 - 28 November 2010, 3 - 6 December 2010 and 25 - 27 November 2011 and 2-4 December 2011), 3) first two non-hunting splits ([SPLIT] 29 November - 2 December 2010, 7 - 8 December 2010 and 28 November - 1 December 2010, 5 - 6 December 2011), 4) main hunting season ([HUNT2] 9 December 2010 - 30 January 2011 and 7 December 2011 - 29 January 2012), and 5) post hunting season ([POST] 31 January - 15 March 2011 and 30 January - 14 March 2012). Additionally, daily survival rates may be better explained by time periods of open or closed waterfowl hunting season rather than the aforementioned time periods. Therefore, I also tested hunted (HUNT1 + HUNT 2) and non-hunted (PRE + SPLIT + POST) periods.

Body condition of non-breeding waterfowl can influence survival of birds, including wintering mallards (Ringelman and Szymczak 1985, Bergan and Smith 1993,

Link 2007, Davis et al. 2011). To maintain consistency with previous research and investigate this metric in my study, I calculated a body condition index to account for individual differences in lipid stores, body mass, and structural size (Whyte and Bolen 1984*a*). I performed principal component analysis (PROC PRINCOMP; SAS Institute Inc. 2011) on flattened wing chord and tarsus measurements. I subsequently used the first principal component score (PC1; hereafter SIZE) as a measure of body size for each marked individual. I regressed (PROC GLM; SAS Inst. Inc. 2011) female body mass on SIZE and calculated an individual body condition score (i.e., condition index; COND) for each female by adding her individual residual value from the regression to the mean mass of all females (Ankney and Afton 1988, Link 2007, Davis et al. 2011). Lastly, I conducted a 2-way Analysis of Variance (ANOVA; PROC GLM; SAS Inst. Inc. 2011) using COND as the dependent variable with explanatory variables of age, winter, and their interaction (Link 2007).

Because body mass or condition of a bird at capture represents one data point per individual at the time of capture, I investigated how bird condition relative to timing of capture during winter might affect individual survival. In previous research of captive wild-strain female mallards fed completely nutritional diets ad libitum, body mass declined 3-7% as winter progressed, suggesting an endogenous mechanism influencing body mass regardless of the amount of quality food and water provisioned to birds (Reinecke et al. 1982, Whyte and Bolen 1984*a*, Baldassarre et al. 1986, Perry et al. 1986, Loesch et al. 1992). Given these factors and that I captured females for 2.5 months each winter, I rationalized that an adjustment in body condition relative to capture date was warranted. Therefore, I combined data by winter and age and regressed (PROC GLM;

SAS Inst. Inc 2011) female COND on Julian capture date to test for evidence of a change in COND through the capture period. If this regression was significant ($P < 0.05$), then I used the residual values from each individual female as a measure of her body condition (CONDRES) in my survival analysis.

The multistate capture-recapture with dead recovery model was developed as a merger of the Seber (1970) band recovery model and the multistate model of Brownie et al. (1993; Barker et al. 2005, White et al. 2006). I used this model in program MARK (White and Burnham 1999, White et al. 2006) to analyze a set of 53 *a priori* conceived models to test whether winter (2010-11 vs. 2011-12), diurnal habitat use (AG, S-EM, FO, P-W), season covariates (PRE, HUNT1, SPLIT, HUNT2, POST), female age (HY, AHY), and body condition adjusted for date of capture (CONDRES) influenced survival of female mallards radio-marked in winters 2010-2012.

The multistate capture-recapture with dead recovery model is used to estimate four parameters which include survival (S), detection probability (p), transition probability (psi [ψ]), and a conditional reporting rate (r; White et al. 2006). I was most interested in survival, therefore, I modeled parameters r, p, and psi in sequence using *a priori* model sets (Breininger et al. 2009). For example, I focused on the modeling of r using a model set in which survival, detection probability, and transition probability were modeled generally (i.e., WINTER+HAB+SEAS+AGE+CONDRES). The most parsimonious model for reporting rate was then used in all subsequent models developed for the remaining variables. The next model set focused on detection probability and included general models of survival and transition probability and the predetermined model of reporting rate in subsequent models. I continued this scheme and focused on

survival last because it was the parameter of greatest interest (Breininger et al. 2009). I used the simulated annealing optimization procedure when running models because this method allows increased flexibility in finding the global maximum during likelihood estimation (Goffe et al. 1994). I ranked model sets based on Akaike's Information Criterion adjusted for small sample sizes (AIC_c) and considered all models within 2 ΔAIC_c as competing and meaningful models (Burnham and Anderson 2002).

Caution is warranted when comparing winter survival rates between studies, because the resulting estimate of survival may vary relative to the analytical methods (Davis 2007). I was interested in comparing my survival estimates with those from previous work to detect any temporal or spatial differences in mallard survival in the MAV. Therefore, I used program MICROMORT (Heisey and Fuller 1985) to calculate interval survival rates, because they would be directly comparable to others from the MAV (Reinecke et al. 1987, Davis 2007). In my analysis, I included 7,165 exposure days (mid-November-March) for 113 radio-marked individuals. Similar to Reinecke et al. (1987) and Davis (2007), I also calculated cause-specific mortality rates for hunting and non-hunting mortalities using program MICROMORT (Heisey and Fuller 1985).

Results

I radio-marked 126 female mallards from 18 November 2010 to 24 January 2011 (n = 27 AHY; n = 31 HY) and 13 November 2011 to 23 January 2012 (n = 2 AHY; n = 66 HY). Thirteen females were excluded from analyses as a result of death, transmitter failure, or my inability to locate them during the adjustment period. Of the remaining 113 females, 21 birds (19%) died during the study. I attributed five (24%) mortalities to hunting while the remaining 16 deaths (76%) were from avian, mammalian, or unknown

causes. The frequency of non-hunting mortality occurred similarly during and after hunting seasons. The mean, median, minimum, and maximum number of days non-hunting related mortalities occurred was 46 ± 8 (SE), 41, 6, and 103 days following the adjustment period. Likewise, mean median, minimum, and maximum number of days hunting mortalities occurred was 29 ± 9, 40, 4, and 47 days following the adjustment period. Similar to Davis et al. (2009), I saw little movement of radio-marked females across the Mississippi River. Of the females that moved west across the river, most remained in habitat contiguous with the river, and I did not detect any females within the study area of Davis et al. (2009; Figure 1.2). Moreover, I detected minimal northward movement of radio-marked females out of the south Mississippi Delta. Of 113 females included in analyses, < 4% were detected ≥1 times north of Mississippi Highway 82, which divides the south and north Mississippi Delta.

From the principal component analysis, SIZE (PCA1) explained 57% of the variation in tarsus and wing-chord lengths among females. Female body mass showed a positive relationship to SIZE (PC1; $F_{1, 111} = 12.44$, $P < 0.001$, $R^2 = 0.10$) with the resulting predictive equation being:

$$\text{Mass} = 1092.61 + 31.12\ (\text{SIZE}) \qquad 1.1$$

Results of the 2-way ANOVA indicated no detectable difference in COND due to neither age ($F_{1, 111} = 2.92$, $P = 0.09$), winter ($F_{1, 111} = 0.20$, $P = 0.65$), nor their interaction ($F_{3, 109} = 1.11$, $P = 0.35$). However, body condition declined with capture date through winter ($F_{1,111} = 28.51$, $P < 0.001$). Therefore, I used each female's residual value calculated from the above regression as a measure of her body condition (CONDRES). Residual values provided a condition estimate relative to the predicted value at the time

of capture; therefore, a positive value indicated a female was in better than expected condition at the time of her capture and vice versa relative to others in the sample population.

Survival

The global model containing all potential covariates received greatest support in explaining daily survival rates of mallards (w_i = 1.00; Table1.1). Daily survival rates ranged between 0.51 and 1.00 depending on habitat type, time period, and year (Table 1.2). Daily survival rates were positively correlated with body condition, and juvenile females had greater survival rates than adult females (Figure 1.3).

In winter 2010-2011, daily survival rates during PRE, HUNT1, and SPLIT were 1.00 for all habitats with the exception of permanent water during HUNT1 (0.96). During HUNT2 in winter 2010, birds using moist-soil and forest habitats had 100% daily survival, whereas birds in agriculture and permanent water had 99.3% and 97.7% daily survival, respectively. Females survived greatest in agricultural habitats (0.99) during POST in winter 2010-2011, followed by permanent water (0.99), forested (0.97), and moist-soil (0.96) habitats.

In winter 2011-2012, the daily survival rate was 1.00 for all habitats during PRE, HUNT1, and SPLIT, with the exception of permanent water during PRE (0.51). Females survived greatest in moist-soil habitats (1.00) during HUNT2 in winter 2011-2012, followed by forested (1.00), permanent water (0.99), and agricultural habitats (0.99). Lastly, during POST in winter 2011-2012, moist-soil habitats had 99.8% daily survival, forested 99.5% permanent water 99.5%, and agriculture 98.9%.

Based on female age, body condition at capture, and the expected number of days spent in each habitat during each time period, the interval survival rates for PRE, HUNT1, SPLIT, were 1.00 in both winters. Survival during HUNT2 was 0.85 and 0.86 and during POST was 0.53 and 0.83 for winters 2010-2011 and 2011-2012, respectively. The average survival rate for the entire 120 day winter period for both winters combined was 0.60 (± 0.02 SE). Average winter survival rates were greater in winter 2011-2012 (0.72; range 0.46–0.87) than in winter 2010-2011 (0.45; range 0.12–1.00).

The constant daily survival rate calculated using Program MICROMORT was 0.997 ± 4.07e-7 resulting in a winter survival rate of 0.70 ± 0.003 (SE) through the wintering period (Table 1.3). Cause-specific mortality rates were 0.23 ± 0.002 and 0.07 ± 0.0009 for non-hunting and hunting related mortality sources, respectively.

Discussion

Understanding factors that influence survival during the non-breeding season is important to the ecology and management of mallards in the MAV and other Joint Venture regions with dominant agricultural landscapes (e.g., Smith et al. 1989). Several studies have related survival of female mallards to body condition, age, season, and winter of study in the MAV (Reinecke et al. 1987, Dugger et al. 1994, Davis et al. 2011). Researchers have conjectured that survival is linked to specific habitat use, but none have empirically tested such a relationship for waterfowl (Kaminski et al. 1985, Fleskes et al. 2007, Davis et al. 2009, Davis et al. 2011, J. M. Tirpak LMVJV, unpublished report). Results from my study indicate that habitat use, winter, within-winter time periods, age, and body condition influenced daily survival rates of female mallards in the south Mississippi Delta during winters 2010-2012.

Reward bands and VHF transmitters have been used to estimate non-breeding season survival of mallards in North America. There is great variability in estimates of survival between these approaches, ranging between 49 and > 99% (Blohm et al. 1987, Reinecke et al. 1987, Bergan and Smith 1993, Dugger et al. 1994, Fleskes et al. 2007, Davis et al. 2011). Winter survival of female mallards in my study ranged from 45-72% between winters, similar to female mallards wintering in northeast Louisiana (54%; Davis et al. 2011). Moreover, survival results were comparable to those for female mallards in the Sacramento Valley of California (49-80%; Fleskes et al. 2007).

However, caution is warranted when comparing estimates of survival among studies of mallards in the MAV due to differences in statistical methodology (Davis et al. 2011). For this reason, Davis (2007) and I also used the Heisey and Fuller (1985; hereafter HF method) method to enable comparison of survival of our mallards to those studied by Reinecke et al. (1987). When applying the HF method, over-winter survival of mallards in my study was 70%, similar to 67% for mallards in Louisiana (Davis 2007) but less than 82% for females in Mississippi and Arkansas in the mid-1980s (Reinecke et al. 1987). The HF method calculates interval survival as a daily survival rate raised to the power of the number of days in the interval (Mayfield 1961, Heisey and Fuller 1985). Therefore, assuming constant daily survival during the entire tracking period and respective interval lengths of 70, 136, and 120 days (Reinecke et al. 1987, Davis 2007, this study), daily survival rates for each study were nearly identical (0.9972, 0.9971, and 0.9971; Table 1.3).

Most female mortalities in my study resulted from non-hunting sources as opposed to direct harvest or hunting-related sources. Davis (2007) reported a similar

trend in his study of female mallards in northeastern Louisiana, whereas the opposite trend occurred in north Mississippi, Arkansas, and southwestern Louisiana (Reinecke et al. 1987, Link 2007). Several factors may influence harvest and natural mortality of female mallards during winter. Mean capture dates in each winter of my study were beyond the midpoint of the waterfowl hunting season; therefore, ~ 66% of my radio-marked individuals may have been subjected to hunting for less than half of the hunting season (i.e., ≤30 days). Moreover, female mallards in this and Davis's (2007) studies used forested wetlands especially diurnally, perhaps to evade hunters when hunting was ongoing. At night, females mostly used moist-soil wetlands; Anderson and Smith (1999) attributed high use of moist-soil habitats nocturnally by mallards as a means to avoid avian predators, but moist-soil wetlands also function as foraging and roosting habitats (Hagy and Kaminski 2012).

Daily survival of mallards in my study was positively correlated with body condition at capture, similar to other studies of wintering mallards (Bergan and Smith 1993, Link 2007, Davis et al. 2011) and northern pintails (Moon and Haukos 2006). Captive wild strain mallards provided a completely nutritious diet ad libitum lost 3-7 % of their body weight during winter, suggesting a loss of endogenous lipid and other nutrient reserves regardless of availability of food and water (Loesch et al. 1992). In the wild, reduced endogenous reserves may have evolved as a result of predictable food resources, mild temperatures, and predation risks in wintering areas (Baldassarre et al. 1986, Lima 1986, Witter and Cuthill 1993, Jamieson et al. 2006). Additionally, leaner birds have reduced existence cost, spend less time feeding, and may be more adept to predator avoidance (Lima 1986, Loesch et al. 1992). However, this interpretation only

holds true if body condition is maintained above some threshold; individuals in poor condition may be inclined to invest more time in feeding than on avoidance of predators or hunters (Fleskes et al. 2002). Studies also have shown that capture using baited traps may be biased toward birds in lower body condition, especially later in winter (Weatherhead and Greenwood 1981, Weatherhead and Ankney 1984, Burnham and Nichols 1985, Weatherhead and Ankney 1985). Female body condition at capture was negatively correlated with capture date in my study consistent with the concept of endogenous loss of reserves through winter but exogenous factors also may have influence winter weight loss. Mallards begin to increase body mass in early spring (February-March; Whyte et al. 1986), and females in poorer condition need to spend increased time foraging to increase reserves in preparation for spring migration. Consequently, increased foraging time may be correlated with predation risk, perhaps resulting in lower daily survival rates during late winter (POST).

Similar to previous research, I observed that daily survival was influenced by age, but, unlike Reinecke et al. (1987), juvenile females in my study survived at greater rates than adult females. I attribute this pattern to capturing mostly juvenile birds in winter 2011-2012 following a record hatch on the breeding grounds in 2011 (Jorde et al. 1984, U. S. Fish and Wildlife Service 2011). Also, weather patterns varied markedly during my study; winter 2010-2011 was cold and dry, while winter 2011-2012 was mild and wet. In fact, from December 2011 through February 2012, there were 19 fewer nights below freezing, and average low temperatures were 7 degrees warmer than during the same period in winter 2010-2011. Moreover, cumulative rainfall was 15 cm below and 5.5 cm above the long-term average for November-March 2010-2011 and 2011-2012,

respectively. Improved wetland conditions in winter 2011-2012 may have contributed to increased female survival that winter. Likewise, Reinecke et al. (1987) attributed greatest winter survival of radio-marked mallards to a mild winter with nearly 40% above normal precipitation. Above average precipitation in the MAV creates newly flooded habitats, including herbaceous, bottomland hardwood forests, and croplands increasing the quantity of plant and invertebrate food resources for waterfowl and allowing birds to disperse to emerging wetlands (Reinecke et al. 1987, Cox and Afton 1998*b*, Heitmeyer 2006).

Daily and winter survival of female mallards was influenced by winter, which may have been an influence of disparate weather patterns between years. In contrast, Bergan and Smith (1993) and Davis et al. (2011) failed to detect differences in survival between winters despite birds in their studies experienced severe wet and dry winters in their respective regions. Therefore, weather may not be reliable in explaining differences in survival between winters. Alternatively, the primary capture location and adjacent habitat composition of capture locations differed between winters and may have influenced daily survival rates. Agricultural and forested habitats were most important to mallards diurnally in winter 2010-2011, whereas moist-soil and forested habitats were most important in 2011-2012 (Chapter 2). I used USDA National Agriculture Statistics Service (2012) data to delineate habitat complexes in a 25 km radius encircling primary capture areas because radio-marked birds primarily remained within 25 km of their capture site. At Muscadine in winter 2011-2012, surrounding habitat was 64 % agricultural and 18 % forested land, whereas Howard Miller WMA was surrounded by 46 % agricultural and 35 % forested lands, and Mahannah was surrounded by 21 %

agriculture and 58 % forested habitats (Table 1.4). Therefore, agriculture dominated the landscapes around Muscadine and Howard Miller WMAs where I radio-marked 92 % of females in winter 2010-2011, and forested habitat dominated around Mahannah WMA where I captured 90% of females in winter 2011-2012. Habitat composition contrasted within the 25 km buffer of each WMA, but it is unknown how much of these areas were flooded and thus available to radio-marked mallards. Nonetheless, habitat composition within the buffer was representative of the region in which the birds were captured and tracked but the difference between years may have influenced survival rates each winter.

Similar to studies of radio-marked mallards in Louisiana, period of the waterfowl hunting season influenced mallard survival in Mississippi (Link 2007, Davis et al. 2011). Interval survival within PRE, HUNT1, and SPLIT periods was 100% in both winters, while HUNT2 interval survival was 85 and 86% in winters 2010-2011 and 2011-2012, respectively, and POST period survival was 53 and 83% in winters 2010-2011 and 2011-2012, respectively (Table 1.5). Unlike Davis et al. (2011), I did not observe decreased survival during the first hunted interval (HUNT1). All females tracked during HUNT1in both years were radio-marked at Muscadine WMA, and following opening of hunting season (HUNT1), they dispersed approximately 10 km south to Yazoo NWR. All of Yazoo NWR is a sanctuary, which likely contributed to high survival for birds using this refuge during this period. Survival during HUNT2 was greater in my study than reported during an analogous period in Louisiana (Davis et al. 2011) despite being approximately one week longer in Mississippi. Season length is unlikely to impact mortality from hunting sources, because Davis (2007) found that mortality during season was more likely to occur early in the season.

Interval survival was least after closure of hunting seasons (POST). A similar pattern was reported in Louisiana (Davis et al. 2011). However, Dugger et al. (1994) detected no mortalities of radio-marked female mallards after the closure of hunting season in Arkansas in springs 1988 and 1989. I recorded 6 mortalities in winter 2010-2011 and one in winter 2011-2012 after the hunting season. Weather varied markedly during POST between winters, possibly causing increased mortality rates in winter 2010-2011. The average minimum temperature during February was slightly colder in winter 2010-2011 (3.6 °C) than in winter 2011-2012 (5.7 °C). However, in February 2012, the minimum temperature was below freezing on only 3 occasions, while subfreezing temperatures occurred on 10 days in February 2011. In fact, there were three consecutive days in February 2011 when the maximum temperatures did not exceed 0° C. Moreover, 7.6 cm of snow fell on 10 February 2011. Whyte and Bolen (1984*b*) estimated that female mallards could survive 5-6 days without food if weather conditions prevented foraging. However, Bergan and Smith (1993) reported that even brief (<5 days) intervals of subfreezing temperatures negatively influenced survival of radio-marked mallards in the Playa Lakes Region of Texas. Freezing temperatures also may force mallards to deeper permanent water habitats where survival was lowest in my study. However, radio-marked females did not leave the study area during these cold and snowy periods as seen in other regions during drastic weather changes (Reinecke et al. 1987, Bergan and Smith 1993). Ice, snow cover, and possible ingress of other mallards from northerly latitudes may have reduced forage availability and increased competition for food (Thomson et al. 2003, Schummer et al. 2010).

Agricultural habitats had the greatest average daily survival rate among hunting and non-hunting periods in winter 2010-2011, followed closely by forested and moist-soil habitats. In winter 2011-2012, moist-soil habitats had the greatest average daily survival among periods, followed by forested and agricultural habitats. Martin (1995) reported that birds are more influenced by direct survival threats (i.e., predation, harvest) than food limitation. Therefore, although forage was likely markedly different among habitat types (e.g., Stafford et al. 2006, Kross et al. 2008, Foster et al. 2010, Straub 2012), differences in survival may be linked to other habitat features that influence detection or avoidance of predators and hunters. Currently, however, I am unaware of any information directly linking duck use or avoidance of habitats to predators in the MAV. Similar results from St. James et al. (2013) and my study in the same geographical region and time frame indicate that mallards and other ducks abandon foraging habitats in response to hunting disturbance.

Flooded agricultural habitats are thought to provide primarily food resources important to wintering waterfowl (Reinecke et al. 1989, Manley et al. 2004), but they also provide expansive areas for loafing and maintenance activities (Chabreck et al. 1989). Waterfowl in large open agricultural habitats may have reduced thermoregulatory costs through unobstructed exposure to sunlight and high visibility for detection of predators and other disturbances (Chabreck et al. 1989). Additionally in flooded agricultural fields, several species of waterbirds are typically present concurrently in large concentrations (Twedt and Nelms 1999, Marty 2013); thus, predator surveillance and detection may be heightened and reduced individual vulnerability (Clark and Mangel 1986, Pöysä 1987, Anderson and Titman 1992). Moreover, flooded monotypic agricultural fields may not

attract natural predators, perhaps except raptors searching for injured birds such as northern Harrier (*Circus cyaneus*) or Bald Eagles (*Haliaeetus leucocephalus*; Preston 1990, Peterson et al. 2001).

Moist-soil wetlands are generally considered quality foraging habitat, because they provide a diverse community of plant and invertebrate foods for waterfowl (Reinecke et al. 1989, Kross et al. 2008, Hagy et al. 2011, Fleming et al. 2012, Hagy and Kaminski 2012). However, Hagy (2010) reported that waterfowl did not abandon moist-soil wetlands when seed abundances declined to apparent giving-up density of seeds in winter suggesting other benefits of moist-soil wetlands to waterfowl besides forage. Mallards using moist-soil habitats may have survival advantages over those in other habitats and thus continue foraging there because of lower predation risk. The interspersion of vegetation and open water in these wetlands provide microhabitats for foraging, thermoregulation, isolation, courtship (Kaminski and Prince 1981, Reinecke et al. 1989) but also vantages for detection of aerial and terrestrial predators (Anderson and Smith 1999, Smith et al. 2004). Moreover, the absence of woody vegetation that typically serves as perches for avian predators may reduce depredation mortality in moist-soil habitats (Preston 1980).

Forested wetlands in my study consisted of scrub-shrub, reforested lands (WRP), bottomland hardwoods, green tree reservoirs, and cypress-tupelo swamps. Each of these resources provides unique suites of resources for mallards in the MAV. Forested habitats are important to wintering mallards given birds' extensive use of them (Kaminski et al. 1993, Davis et al. 2009, Chapter 2) and low propensity to depart these habitats nocturnally (Davis and Afton 2010). Daily survival rates of mallards using forested

wetlands averaged 0.996 and were surpassed only by croplands in winter 2010-2011 and moist-soil wetlands in 2011-2012. Forested habitats may act as refuge from anthropogenic and natural predator disturbances (Baldassarre and Bolen 2006). Canopy structure in forested habitats may provide concealment and obstruction from aerial predators. Mallards are typically found in pairs or small flocks in forested wetlands and may attract less attention from predators as larger groups found in agricultural habitats (Dell et al. 1987). Davis and Afton (2010) found that female mallards located in forested or reforested habitats diurnally were likely to remain in these habitats >88% time nocturnally. Therefore, females that remain in forested habitats nocturnally may have decreased mortality because of reduced exposure to natural predators.

Daily survival rates were least in permanent wetlands during both winters. Permanent wetlands, including oxbow lakes, rivers, and aquaculture ponds generally with depths >1 m, likely provide little accessible food to wintering dabbling ducks, except northern shoveler (*A. clypeata*) and gadwall (*A. strepera*; Dell et al. 1987, Dubovsky and Kaminski 1987, Reinecke et al. 1989). Most permanent wetlands exceed a mean water depth of ≤16 cm, which Hagy and Kaminski (2012) found mallards and other dabbling ducks foraged frequently in moist-soil wetlands. However, permanent water can provide important roost or loafing areas to ducks especially during cold or dry periods during winter (Jorde et al. 1984, Christopher et al. 1988). Permanent water also lacks canopy cover or vegetative structure that may protect birds from predators or aid in thermoregulation. However, because of mallard's gregarious nature during the non-breeding season (Owen and Black 1990, Legagneux et al. 2009), they may be attracted to

permanent water habitats by the presence of con- or heterospecific waterfowl (Elmberg et al. 1997, Thomson et al. 2003).

As with any mark-recapture study, there are potential sources of bias that should be discussed. Blohm et al. (1987) reported lower survival rates for male mallards banded on areas open to waterfowl hunting than on sanctuary areas. Given that I captured and radio-marked females on areas open to hunting, my survival estimates may be negatively biased. Moreover, Withey et al. (2001) reported negative effects among studies testing backpack harness transmitters among waterfowl, especially during the breeding season (Pietz et al. 1993, Garrettson et al. 2000) and on diving ducks (Aythya spp.; Perry 1981). However, Dwyer (1972) style backpack transmitters have been used extensively in studies of wintering and migrating ducks and should not be a significant source of bias on survival estimates (Link 2007, Pearse et al. 2011). Moreover, 5 female mallards radio-marked in my study in winter 2010-2011 were harvested during subsequent autumn at locations up to 2,000 km from capture locations.

Future research should identify habitat specific activity budgets and their potential of influencing survival rates. Use of unmanned aircraft (i.e., drones) may be useful technology to acquire these data diurnally and nocturnally (Farrell 2013). Moreover, survival studies should include a measure of avian predator abundance in the study area during the study. Additionally, because non-hunting mortality appears to be the greatest source of mortality, researchers should study predation rates from varying sources (Peterson et al. 2001). For example, transmitter designs that include 8 hour mercury type mortality switches regularly will not emit a mortality signal until it is separated from the waterfowl carcass or all tissue is consumed. This limitation can lead to erroneous

conclusions regarding the actual cause of mortality if scavenging predators move the carcass after death (Peterson et al. 2001). Identification of primary predators to wintering waterfowl can influence the design of wetlands to reduce such predation (i.e., reduction of raptor perches; Link 2007).

Management Implications

Davis et al.'s (2011) and my yearly survival estimates, ranging from 45-72%, were lower than non-breeding season estimate of 80% used by Hoekman et al. (2002) to calculate the influence of winter survival on population growth. If our estimates are accurate and representative of mallards wintering in the MAV today, Hoekman et al. (2002) may have underestimated the influence of winter survival on mallard population growth. Negative influences on population growth may be amplified if changes in hydrology continue to be directed toward flood control projects, or policy that limits or reduces pumping ground water for flooding waterfowl impoundments during winter (Popp et al. 2010, Cooper 2012). Either of the aforementioned changes could reduce the availability of flooded moist-soil, agriculture, or forest habitats which may cause mallards to use permanent or open wetlands where increased mortality occurs or geographical shifts to different regions of the MAV or beyond.

Future management should focus on enhancing the amount and quality of wetlands on the landscape during winter. Specifically, focus should be directed toward flooding post-harvest agricultural fields, promoting moist-soil management, and flooding forested wetlands including bottomland hardwoods and scrub/shrub habitat. These can be deemed "suitable" habitats (sensu Fretwell 1972) in that they are important to mallards and other ducks and mallard survival is increased by use of these wetlands (Reinecke et

al. 1989, Davis et al. 2009, this study). Many agricultural fields in the Mississippi Delta are land leveled and thus require minimal water to flood to desirable depths for waterfowl (<16 cm; Hagy and Kaminski 2012). Managers could also direct manage water levels in permanent wetlands with water control structures to promote the growth of emergent vegetation around wetland perimeters (Schummer et al. 2012). Incentive based programs through the NRCS should continue to focus on compensating landowners to provide flooded agricultural fields and other managed wetlands during the winter, thus benefitting survival of mallards especially during cold and dry winters.

Table 1.1 Daily survival model selection results.

Model Name[a]	k[b]	AICc	ΔAICc	AICc Weight
YR+HAB+SEAS+AGE+CONDRES	192 (42)	15981.6	0.0	1
CONDRES	152 (2)	16367.3	385.7	0
OPNvs.CLSD+AGE+CONDRES	154 (4)	16421.4	439.8	0
HAB+AGE+CONDRES	156 (6)	16469.5	487.8	0
OPNvs.CLSD	152 (2)	16479.5	497.8	0
HAB	154 (4)	16492.7	511.0	0
SEAS+AGE+CONDRES	157 (7)	16494.5	512.9	0
HAB+OPNvs.CLSD+AGE+CONDRES	160 (10)	16511.3	529.7	0
AGE+CONDRES	153 (3)	16517.7	536.1	0
…	…	…	…	…
NULL	151 (1)	16543.1	561.5	0

[a] AGE = female age (juvenile or adult), CONDRES = size adjusted body mass adjusted for capture date, HAB = occupied habitat type, SEAS = hunting season (PRE, HUNT1, SPLIT, HUNT2, and POST; see methods for description), CLSD = closed hunting season (PRE, SPLIT, and POST), and OPN = open hunting season (HUNT1 and HUNT2) YR = winter of study (2010-2011 and 2011-2012).

[b] Number of estimated parameters. Estimated survival parameters only, in parentheses.

For radio-marked female mallards captured at three Wildlife Management Areas in the south Mississippi Alluvial Valley in Mississippi during winters 2010-2011 and 2011-2012.

Table 1.2 Daily survival rates of radio-marked female mallards.

		Agriculture			Moist-Soil			Forested			Permanent Water		
Year	Season[a]	Survival	LCI[b]	UCI[c]	Survival	LCI	UCI	Survival	LCI	UCI	Survival	LCI	UCI
2010-2011	PRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	HUNT1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.72	0.99
	SPLIT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	HUNT2	0.99	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.96	0.99
	POST	0.99	0.96	1.00	0.96	0.90	0.98	0.97	0.94	0.99	0.99	0.97	1.00
2011-2012	PRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.51	0.51	0.51
	HUNT1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	SPLIT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	HUNT2	0.99	0.95	1.00	1.00	1.00	1.00	1.00	0.98	1.00	0.99	0.96	1.00
	POST	0.99	0.89	1.00	1.00	0.96	1.00	1.00	0.98	1.00	1.00	0.97	1.00

[a] See methods for description of season abbreviations.

[b] Lower confidence limit.

[c] Upper confidence limit.

For mallards captured at three Wildlife Management Areas in the south Mississippi Alluvial Valley in Mississippi during winters 2010-2011 and 2011-2012.

Table 1.3 Comparison of Heisey and Fuller (1985) winter survival estimates from this study and those of Reinecke et al. (1987) and Davis (2007).

Location	Years	Winter Survival	Days in Winter	Daily Survival[a]	Hunting[b]	Non-Hunting[b]
AR / MS[c]	1980-1985	0.82	70	0.9972	0.13	0.06
LA / AR[d]	2004-2006	0.67	136	0.9971	0.16	0.17
MS[e]	2010-2012	0.70	120	0.9971	0.07	0.23

[a] Daily survival rate assuming constant survival through the entire winter.

[b] Cause specific mortality rates for hunting and non-hunting related deaths.

[c] Reinecke et al. (1987).

[d] Davis (2007).

[e] This study.

Table 1.4 Proportions of habitats within a 25-km radius surrounding Wildlife Management Areas.

Habitat[a]	Muscadine Farms	Howard Miller	Mahannah
NON-HAB	0.06	0.03	0.05
AGRIC	0.64	0.46	0.21
M-SOIL	0.05	0.07	0.07
FOREST	0.18	0.35	0.58
OPN-WAT	0.07	0.08	0.09

[a] NON-HAB = developed and industrial non habitat, AGRIC = agriculture, M-SOIL = fallow agriculture and seasonal emergent vegetation, FOREST = forested and scrub-shrub habitats, OPN-WAT = rivers, aquaculture facilities, and lakes.

Wildlife Management Areas in the Mississippi Alluvial Valley in Mississippi, where female mallards were captured and radio-marked during winters 2010-2011 and 2011-2012.

Table 1.5 Interval survival rates by season and year.

Year	Season[a]	Interval Length	Survival	SD	Min	Max
2010-2011	PRE	10	1.00	0.00	1.00	1.00
	HUNT1	7	1.00	0.00	1.00	1.00
	SPLIT	6	1.00	0.00	1.00	1.00
	HUNT2	53	0.85	0.14	0.48	1.00
	POST	44	0.53	0.30	0.20	1.00
2011-2012	PRE	9	1.00	0.00	1.00	1.00
	HUNT1	6	1.00	0.00	1.00	1.00
	SPLIT	6	1.00	0.00	1.00	1.00
	HUNT2	54	0.86	0.06	0.73	1.00
	POST	45	0.83	0.07	0.61	1.00

[a] See methods for season abbreviations.

For radio-marked female mallards captured at three Wildlife Management Areas in the south Mississippi Alluvial Valley in Mississippi during winters 2010-2011 and 2011-2012.

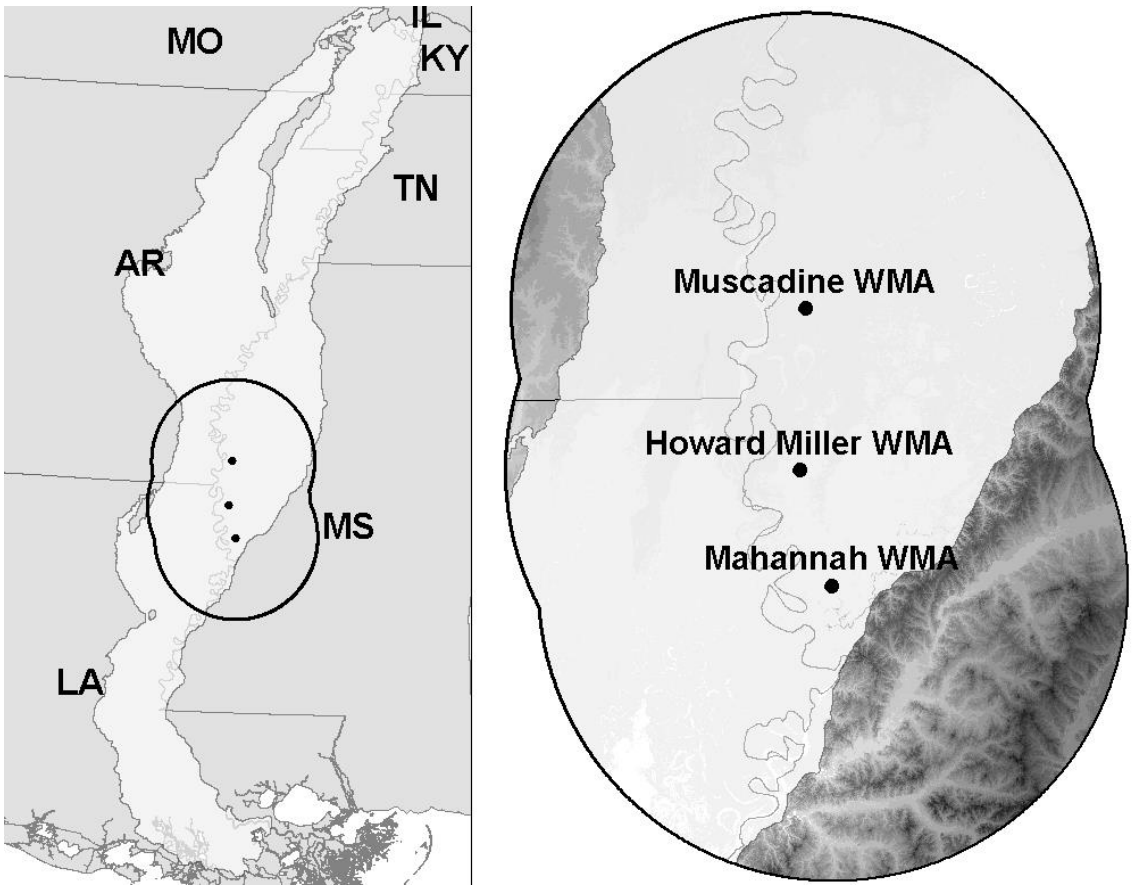

Figure 1.1 Locations where female mallards were captured, radio-marked and tracked.

Capture locations (black dots) on Wildlife Management Areas (WMA) in the Mississippi portion of the Mississippi Alluvial Valley and 80 km surrounding search area (black circle) during winters 2010-2012.

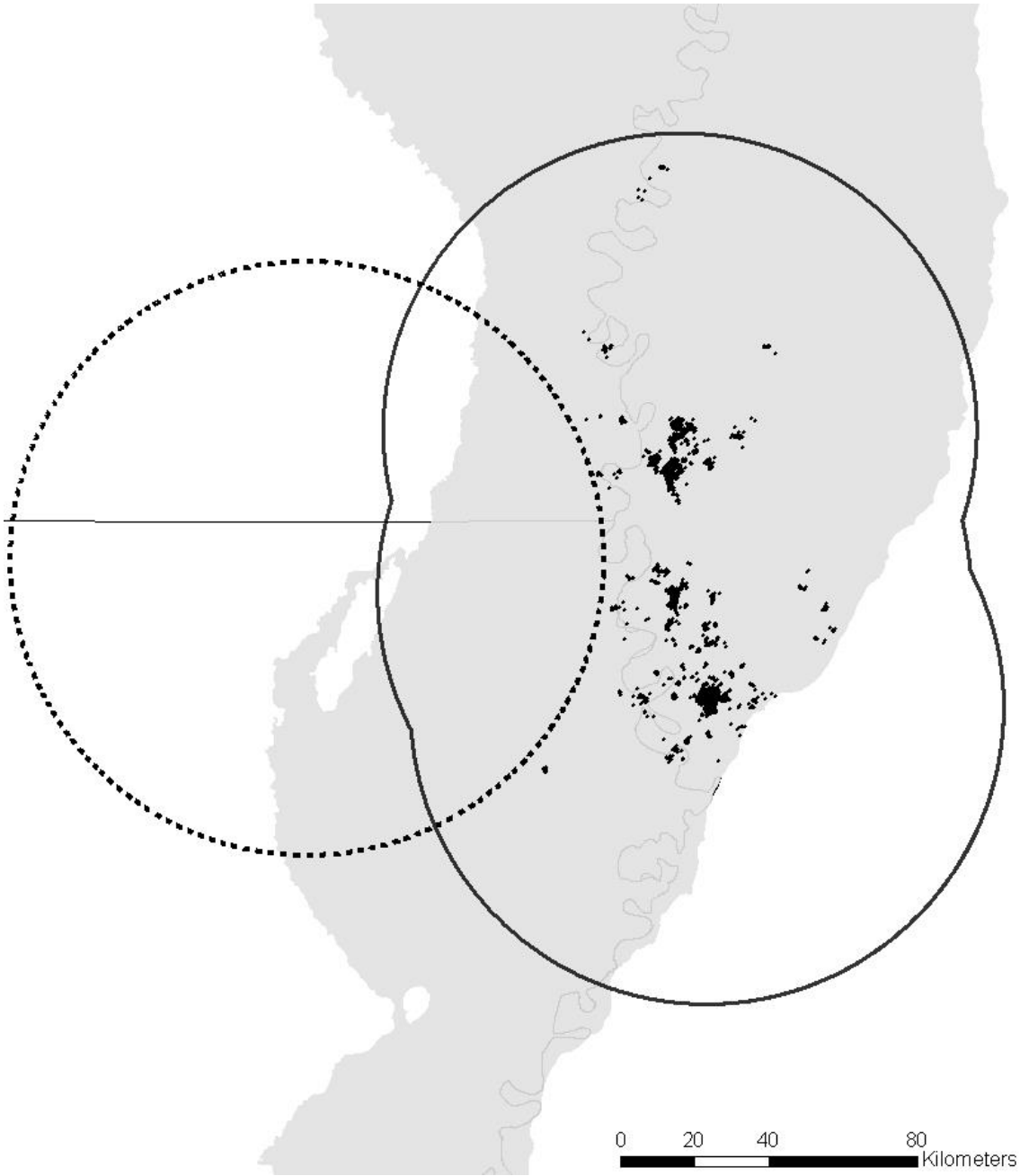

Figure 1.2 Study-area overlap between my study area (solid circle) and locations (black dots) of radio-marked female mallards to that of Davis et al. (2009; broken circle) within the south Mississippi Alluvial Valley.

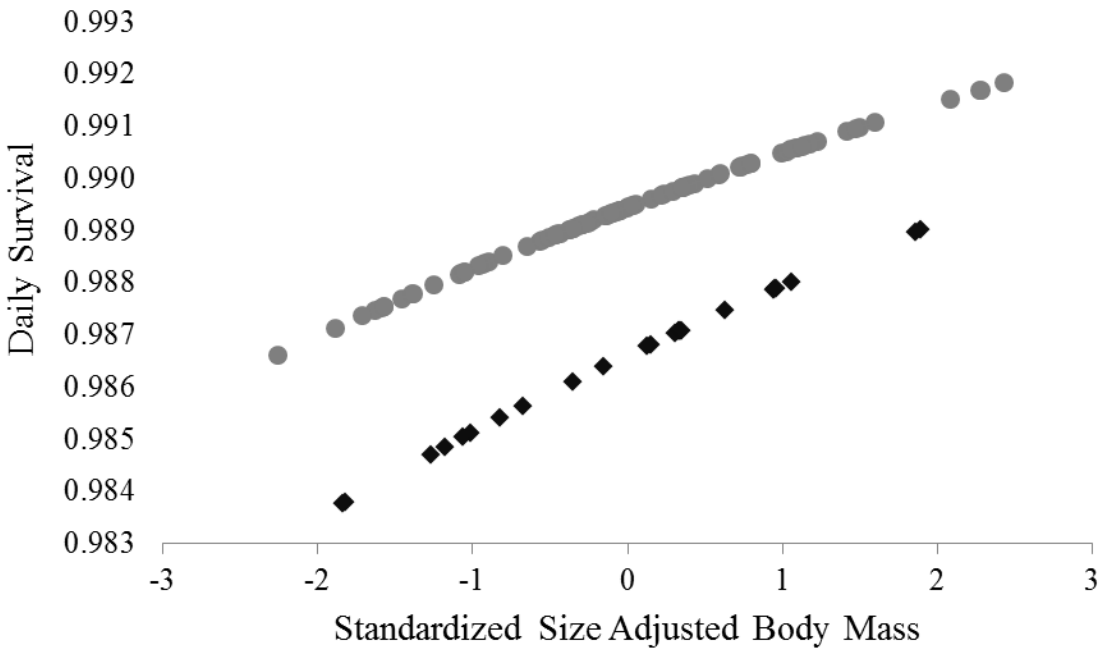

Figure 1.3 Influence of female age (juvenile [gray] and adult [black]) and standardized size-adjusted body mass on daily survival.

Within moist-soil habitats post hunting season for radio-marked female mallards captured at three Wildlife Management Areas in the south Mississippi Alluvial Valley in Mississippi during winters 2010-2011 and 2011-2012.

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CHAPTER II

HABITAT USE BY FEMALE MALLARDS IN MISSISSIPPI'S ALLUVIAL VALLEY

Species conservation seeks to identify and conserve habitats and associated resources that promote survival, reproduction, and sustain populations (Fretwell and Lucas 1970, Johnson 1980, Garshelis 2000). The annual cycle of waterfowl (family Anatidae) consists of breeding and non-breeding periods, often in disjunct regions of North America for migratory species (Nichols et al. 1983, Baldassarre and Bolen 2006). Survival of females, nests, and ducklings during the breeding season generally has the greatest influence on population growth rates of Nearctic ducks (Hoekman et al. 2002, Amundson et al. 2011). However, events occurring during winter are not inconsequential and ultimately may influence individuals' fitness (Heitmeyer and Fredrickson 1981, Kaminski and Gluesing 1987, Davis et al. 2011). For example, increased winter precipitation in the Mississippi Alluvial Valley (MAV), snow cover, and decreased temperatures north of the MAV were correlated with mallard (*Anas platyrhynchos*) abundance in the MAV during winter or indices of subsequent recruitment rates (Heitmeyer and Fredrickson 1981, Nichols et al. 1983, Kaminski and Gluesing 1987, Heitmeyer 2006, Pearse 2007, Schummer et al. 2010).

The MAV lies within the southern portion of the Mississippi Flyway and is arguably the most important single region for non-breeding mallards in North America, as > 40% of mallards in the flyway use this region during autumn and spring migration

and winter (Bellrose 1976, Nichols et al. 1983, Davis et al. 2011, Pearse et al. 2012). Most of the 10 million ha MAV was comprised of bottomland hardwood forest until the early 20th century. Timber harvest and clearing, primarily for agriculture, has resulted in < 2.8 million ha of largely fragmented bottomland hardwood forests today (King et al. 2006). Today, approximately 65% of land in the MAV is cultivated primarily for cotton, corn, soybean, rice, grain sorghum, and wheat; plus, catfish aquaculture is important especially in Mississippi (Dubovsky and Kaminski 1987, Gardiner and Oliver 2005).

Historically, mallards and other waterfowl satisfied their biological and social requirements exploiting resources in bottomland hardwood forests and other wetlands inundated by natural riverine flooding and run-off (Reinecke et al. 1989). Flood control levees and channelization have reduced the frequency and scale of flooding in the MAV (King et al. 2006), so deliberate flooding of bottomland hardwoods, agricultural fields, and restored wetlands (e.g., Wetland Reserve Program [WRP]) provides important habitats for wintering mallards and other wetland birds and wildlife (Reinecke et al. 1989, Dabbert and Martin 2000, Heitmeyer 2006, J. M. Tirpak LMVJV, unpublished report). Mallards are adept at exploiting food resources, often moving among habitats to exploit agricultural and natural seeds, tubers, and aquatic invertebrates (Wright 1959, Delnicki and Reinecke 1986, Combs and Fredrickson 1996, Dabbert and Martin 2000, Davis and Afton 2010, Callicutt et al. 2011).

Several studies have focused on estimation of seed abundance and carrying capacities of agricultural, seasonal emergent, and forested habitats for wintering waterfowl in the MAV (Manley et al. 2004, Stafford et al. 2006, Kross et al. 2008*b*, Foster et al. 2010*b*, Foth 2011, Hagy and Kaminski 2012, Straub 2012). Estimates of

seed abundance are used in bio-energetic models to calculate habitat requirements necessary to support population goals of migrating and wintering waterfowl, because biologists assume that energy may be a limiting factor affecting nonbreeding waterfowl (Loesch et al. 1992 Reinecke and Loesch 1996, Miller and Newton 1999, Miller and Eadie 2006, J. M. Tirpak LMVJV, unpublished report). Thus, habitat management in the MAV has focused on increasing food availability by restoring seasonal emergent wetlands and promoting agricultural practices that benefit waterfowl (Manley et al. 2004, King et al. 2006, Kross et al. 2008 *a,b,* Havens et al. 2009, Fleming et al. 2012, Hagy and Kaminski 2012). In addition to acquiring adequate and nutritious food, waterfowl engage in important social behavior, such as courtship and pair bond maintenance during winter (Paulus 1988, Reinecke et al. 1989, Johnson and Rohwer 1998, Davis et al. 2009). Other environmental and biological factors such as weather, age, and pair- and molt-statuses also may influence resource and habitat use by female mallards in the MAV (Reinecke et al. 1989, Heitmeyer 1985, Heitmeyer 1988, Schummer et al. 2010). Thus, mallards use diverse habitats in the MAV to satisfy requirements and survive during the non-breeding season (Pearse et al. 2012).

Aerial transect surveys were used to estimate abundance and habitat use of mallards wintering in northeastern Louisiana in the 1980s (Dell et al. 1987). Greatest densities of mallards were observed in flooded agricultural fields and open wetlands, whereas few birds were counted in forested wetlands (Dell et al. 1987). Pearse et al. (2012) reported size of mallard groups increased 6% and 3% with each 1% increase in flooded rice and soybean at a landscape scale (5,000 ha), respectively. Davis et al. (2009) studied ecology of radio-marked female mallards in northeast Louisiana and

southeast Arkansas in the MAV. Use of forested wetlands varied by winter and within-winter periods but was highly important diurnally and nocturnally (43-82%). Furthermore, Davis and Afton (2010) reported that females using forested habitats diurnally were less likely to change habitats at night (≤ 22%) than those diurnally located in rice fields (55%). Therefore and contrary to Dell et al. (1987), evidence from individual radio-marked mallards indicated that forested wetlands may be most important to mallards wintering in portions of the MAV (Davis et al. 2009, Davis and Afton 2010). However, Pearse et al. (2008) evaluated visibility bias associated with aerial surveys in disparate habitats and reported detection rates were influenced by flock size in open wetlands but not in forested wetlands. Therefore, habitat use estimates derived from aerial transects may be biased toward large groups (>15 individuals) in open wetlands and negatively for mallards in forests.

Davis et al. (2009), working in northeast Louisiana and southeast Arkansas, found little movement of radio-marked mallards across the Mississippi River into Mississippi. This pattern suggests there may be cohorts or sub-populations of mallards in the MAV that may encounter different intra- and inter-regional selective pressures (e.g., hunting disturbance), which may influence differential habitat use among regions. Additionally, diversity in landscape composition between western and eastern portions of the MAV is evident; nearly one million ha of rice were grown in Louisiana and Arkansas in 2010, whereas only 123,000 ha were grown in Mississippi (United States Department of Agriculture [USDA] National Agricultural Statistics Service 2011). Moreover, habitat composition differed between Louisiana/Arkansas and Mississippi (Davis et al. 2009, this study). Forested habitats dominated Louisiana and Arkansas (66% forested; 16%

agriculture), whereas my study area contained 38% forested and 41% agriculture (USDA National Agricultural Statistics Service 2013). Alternatively, mallards may select wintering locations based on complexes of habitat rather than presence of any single habitat type (Brown and Dinsmore 1986, Fredrickson and Heitmeyer 1988, Pearse et al. 2012).

Pearse et al. (2012) quantified landscape level complexes of habitat that encircled large groups (≥100 individuals) of mallards and other wintering waterfowl in Mississippi. Large groups of mallards were associated with surrounding landscapes that contained approximately 47% flooded agriculture, 20% seasonal emergent wetlands, 20% forested/scrub-shrub wetlands, and 13% permanent wetlands (Pearse et al. 2012). Distinguishing habitat or resource patterns that support abundant waterfowl is applicable for identifying potential inadequacies in habitats within a landscape. For instance, if bottomland hardwood forest is perceived as being inadequate in some locations of the MAV, this knowledge would be an important consideration for future conservation planning, such as afforestation through the WRP (Loesch et al. 1995, King et al. 2006).

Numerous techniques and analyses are available to quantify resource use and selection by marked animals (White and Garrott 1990, Erickson et al. 2001). However, the analytical method of choice can greatly influence results and conclusions, particularly when estimating habitat or resource availability in a region of interest (Garshelis 2000, Buskirk and Millspaugh 2006). Mallards rarely use non-flooded habitats in the MAV as they do in northern regions (Bossenmaier and Marshall 1958, Baldassarre and Bolen 1984, Pearse et al. 2011). Therefore, calculation of true habitat selection by mallards should only consider inundated habitat as ‘available’, as I neither observed unmarked or

radio-marked mallards in non-flooded habitats during my study. However, methodology to quantify real-time inundated habitats is lacking, because hydrology is dynamic in the MAV and high resolution satellite imagery is only available periodically (Taft et al. 2004).

Although Nearctic mallards are well studied (Bellrose 1976, Baldassarre and Bolen 2006), studies of interrelations between resource use, survival, and other life-cycle events during winter in the MAV are relatively few and recent (Reinecke 1987, Dugger et al. 1994, Heitmeyer 2005, Davis et al. 2011, Pearse et al. 2012). Understanding habitat use, spatial distribution, and survival of these birds is fundamental to habitat conservation and hunting management in Mississippi and the MAV. Therefore, I used radio-telemetry to quantify diurnal and nocturnal habitat use by female mallards in western Mississippi.

I realize that multiple factors may influence habitat use of wintering mallards. Therefore, I specifically sought to increase our knowledge of the possible influence of age, within-winter time periods relative to hunting seasons, and winter of capture on diurnal and nocturnal habitat use by these birds. I investigated these possible influences of habitat use because Davis et al. (2009) found influences of winter and within-winter periods for female mallards in Louisiana. Additionally, I compared my results to previous and contemporary research on habitat use by mallards in the MAV (Dell et al. 1987, Reinecke et al. 1992, Davis et al. 2009).

Study Area

I captured mallards at three state-managed Wildlife Management Areas (WMAs) in the southern portion of the Mississippi MAV: 1) Howard Miller WMA is a 971 ha seasonally flooded complex near Rolling Fork, Mississippi (32°49’48.93” N,

90°58’51.61” W), which is annually planted to rice and soybean but also contains seasonal emergent vegetation supplemented with plantings of corn and Japanese millet; 2) Mahannah WMA, near Vicksburg, Mississippi (32°32’54.95” N, 90°52’14.08” W), is a 5,100 ha complex with expansive bottomland hardwoods, scrub-shrub, seasonal emergent vegetation, and rice and soybean. Approximately 80% of Mahannah WMA is seasonally and naturally flooded annually, and the remaining area is managed for upland species primarily white-tailed deer (*Odocoileus virginianus*); and 3) Muscadine Farms WMA, near Avon, Mississippi (33°13’29.32” N, 90°59’01.51” W), is a 607 ha retired catfish pond complex owned by the U.S Army Corps of Engineers. The complex is managed for waterfowl through seasonal vegetation manipulation, supplemental plantings of corn and Japanese millet, and strategic fall-winter flooding of impoundments.

I tracked female mallards in all areas within 80 km of trapping sites, which included portions of northeast Louisiana and southeast Arkansas (Figure 2.1; Cox and Afton 1997, Davis et al. 2009). In addition to trapping locations, the tracking area included publicly owned (Mississippi Department of Wildlife, Fisheries, and Parks [MDWFP]) and managed WMAs (i.e., Charlie Capps, Lake George, Leroy Percy, Shipland, Sky Lake, Stoneville, Sunflower, and Twin Oaks WMAs). State managed lands in the study area outside of Mississippi included Big Lake and Buckhorn WMAs in Louisiana and Casey Jones and Seven Devils Lake WMAs in Arkansas. Federal lands included Dahomey, Hillside, Holt Collier, Mathews Brake, Morgan Brake, Panther Swamp, Theodore Roosevelt, and Yazoo National Wildlife Refuges (NWR) in Mississippi, Delta National Forest in Mississippi, Handy Brake and Tensas River NWRs

in Louisiana, and Overflow NWR in Arkansas. Additional environmental details of the MAV are in the literature (e.g., Reinecke et al. 1989, Baldassarre and Bolen 2006).

Methods

Mallard Capture and Tracking

I captured female mallards from early November 2010-2011 through late January 2011-2012 on WMAs using swim in traps modified from those described by Hunt and Dahlka (1953) or rocket nets fired from portable platforms (Dill and Thornberry 1950, Cox and Afton 1994). Capture sites were baited with rice, soybean, sweet potato, or corn and were located throughout the WMAs prior to hunting season. Ten to 12 days prior to hunting season, all traps and remaining bait in hunting units were removed. Traps were relocated to sanctuaries as distantly as possible from waterfowl hunting areas to eliminate possible effects of bait on duck distribution and hunting.

I designated captured females as juvenile (hatch year; HY) or adult birds (after hatch year; AHY) according to wing plumage characteristics (Carney 1992). I banded each female with a United States Fish and Wildlife Service aluminum leg band and attached a 23 g VHF backpack transmitter (Dwyer 1972). Transmitters had a pulse of 55 beats per minute, had a life expectancy of 150 days, and were equipped with a mercury type mortality sensor that doubled the pulse rate when transmitters were motionless for ≥8 hours. Transmitters weighed 2.1% (± 0.02% [SE], n = 113) of mean female body mass on date of capture. Transmitter weight < 5% of a bird's body mass are thought to prevent physiological or behavioral burden on the individual (Cochran 1980, Casper 2009). I held females 4-6 hours after morning capture and 12-18 hours (overnight) when captured in the afternoon to allow adjustment to the transmitter and ensure proper fit

(Davis et al. 2009). During acclimation periods, birds had access to corn and water ad libitum. I released instrumented females with captured conspecific males or females to minimize possible dissolution of paired birds (Cox and Afton 1998). All capture, handling, and marking methods were approved by the Mississippi State University Institutional Animal Care and Use Committee protocol (# 10-070).

I tracked radio-marked females using trucks equipped with roof-mounted 4-element, null-peak antenna arrays, electronic compasses, Global Positioning System (GPS) units, and laptop computers with Location of a Signal software (LOAS 4.0; Ecological Software Solutions LLC, Hegymagas, Hungary; Cox et al. 2002, Gilsdorf et al. 2007). I calibrated electronic compasses to known locations of beacon transmitters ± 0.5° and trained technicians by triangulating beacon transmitters until they could successfully maintain an azimuth standard deviation of ≤ 3º (Davis et al. 2009). I tracked radio-marked mallards diurnally (30 min before sunrise to 30 min after sunset) and nocturnally (30 min post sunset to 30 min prior to sunrise) throughout the study area, defined as an area of 80 km radius from capture locations (Cox and Afton 1997, Davis et al. 2009). I chose a random radio-marked bird to begin tracking and a random direction so that individual locations were gathered at random intervals. When few females were available for tracking, I randomly chose a time of the day (i.e., morning, mid-day, afternoon) and corresponding nocturnal period to track females. Using a fixed wing aircraft equipped with left and right directional antennas, I pursued radio-marked mallards not detected from trucks after 2 consecutive days. The pilot flew at an altitude of 2,100-2,800 m and descended to 300 m elevation to pinpoint an individual (Gilmer et al. 1981). Upon locating a bird from the air, I recorded GPS coordinates along with

distance and direction to a recognizable landmark and relayed information to technicians in telemetry trucks, so they could locate and triangulate birds' locations. I did not use aerially derived locations in data analyses, because accurate locations of birds were obtained from the ground on the same day following aerial location.

I attempted to record 3 azimuths to calculate each female location, but I continued to add azimuths until error ellipses fell within one habitat type or available vantage points were exhausted. Locations containing ≥ 3 azimuths comprised 96.5% of total locations, although, in some instances, road inaccessibility forced me to use bi-angulations (3.5% of locations) from the best available vantage points. If multiple triangulations occurred for an individual in a day, I used the first location, unless the subsequent location contained more azimuths. The LOAS software estimated point locations for each bird with a maximum likelihood estimator (Lenth 1981) using a bearing standard deviation of 3° (Davis et al. 2009). I examined azimuths and point locations in real-time and immediately discarded apparently erroneous locations and re-triangulated the individual.

Statistical Analyses

I excluded the first three days of exposure (hereafter, adjustment period) following capture and release for each female from analysis to avoid stress induced bias from capture and handling (Cox and Afton 1998). I transferred female locations into a geographic information system (GIS) in ARCMAP 9.3.1 (Environmental Systems Research Institute 2005). I assigned a habitat type within GIS to each location as determined by visual inspection, contact with landowners or managers, or a combination of National Agricultural Imagery Program imagery and United States Department of Agriculture Service Agency records. I categorized daily locations into four habitat types:

1) [AGRIC] flooded agricultural lands including rice, soybean, corn, grain sorghum, and other crops, 2) [MSOIL] seasonal emergent wetlands including wetlands dominated by natural herbaceous plants, moist-soil wetlands, and agricultural fields left fallow during the previous growing season(s), 3) [FOREST] forested wetlands including all wetlands dominated by trees or scrub-shrub (Fredrickson et al. 2005, Pearse et al. 2012), and 4) [OPN-WAT] permanent water including all wetlands that retain water annually including aquaculture ponds, river channels, and oxbow lakes.

During my study, the MDWFP managed a 60-day duck hunting season beginning in late November and ending in late January, with a goal to maximize number of weekends available for hunting. Thus, multiple season splits (i.e., periods of hunting separated by periods of no hunting) were implemented during the hunting season. Similar to Davis et al. (2009), I divided winters into five time periods based on their timing relative to hunting season: 1) period before hunting season ([PRE] 16 - 25 November 2010 and 16 - 24 November 2011), 2) first two hunting periods ([HUNT1] 26 - 28 November 2010, 3 - 6 December 2010 and 25 - 27 November 2011 and 2-4 December 2011), 3) first two non-hunting splits ([SPLIT] 29 November - 2 December 2010, 7 - 8 December 2010 and 28 November - 1 December 2010, 5 - 6 December 2011), 4) main hunting season ([HUNT2] 9 December 2010 - 30 January 2011 and 7 December 2011 - 29 January 2012), and 5) post hunting season ([POST] 31 January - 15 March 2011 and 30 January - 14 March 2012). For habitat use analyses, I only included HUNT2 and POST because late capture of birds prevented adequate sample sizes to analyze data from PRE, HUNT1, and SPLIT periods.

Diurnal and Nocturnal Habitat Use

Some analytical approaches used in habitat use studies regard individual radio locations as the sampling unit, but compositional analysis considers the individual animal as the sampling unit. This approach reduces problems related to sample level, unit sum constraint, and differential use by groups of animals (Kenward 1992, Aebischer et al. 1993). For each individual, I calculated the proportional use of each habitat during HUNT2 and POST periods for diurnal and nocturnal data separately. When necessary, I replaced zero values from unused habitats with 0.002 and 0.004 for diurnal and nocturnal periods, respectively, a positive value one magnitude smaller than the smallest recorded non-zero proportion (Aebischer et al. 1993). I then computed a natural log ratio for all habitats using proportional use of AGRIC as the denominator, thus removing the unit sum constraint (Aitchison 1986). The results of the analysis are independent of the habitat chosen as the ratio's denominator, but allow direct comparison to the habitat chosen as the denominator (Aebischer et al. 1993). Proportional use of AGRIC was chosen as the denominator value, because these habitats have been intensively studied and considered important to migrating and wintering waterfowl in the MAV (Dell et al. 1987, Reinecke et al. 1992, Manley et al. 2004, Stafford et al. 2006, LMVJV 2007, Foster et al. 2010*b*). I used the log ratios as response variables in a split-plot Multivariate Analysis of Variance (MANOVA; SAS INST INC. 2011) to test for influences of individual female, age (AHY or HY), winter (2010-11 or 2011-12), and time period (HUNT2 or POST) and all 2-way interactions. I used split plots to calculate variation associated with individual females as the error term when testing for influences of age, winter and their interaction, and residual error to test for individual female and time

period effects and all other interactions. I began by analyzing full models and subsequently used backward stepwise procedures to eliminate non-significant explanatory variables ($P > 0.05$; Wolfinger 1992).

I subsequently compared proportional use of each habitat by females to use of AGRIC, within levels of significant explanatory variables by testing whether least-square means of log-ratios differed from zero (Cox and Afton 1997, Davis et al. 2009). I present estimates of proportional use of each habitat as averages across individuals to facilitate biological interpretation within levels of significant ($P \leq 0.05$) explanatory variables from the final fitted model (Davis et al. 2009).

Diel Habitat Use

I performed a holistic analysis in which I combined data from diurnal and nocturnal periods and both winters because I was interested in determining diel patterns in habitat use across space- and time-scales of my study. Therefore, I used compositional analysis and MANOVA methods (Proc GLM; SAS INST INC. 2011) similar to those previously described to test for influences of individual female on proportional diel habitat use. I present estimates of proportional use of each habitat as averages across individuals to facilitate biological and management inference making.

Results

I radio-marked 126 female mallards from 18 November 2010 to 24 January 2011 (n = 27 AHY; n = 31 HY) and 13 November 2011 to 23 January 2012 (n = 2 AHY; n = 66 HY). I excluded 13 females from analyses due to their death, transmitter failure, or my inability to locate them during the adjustment period. I excluded 3 additional birds

from analyses because they were not located during HUNT2 or POST time periods. Of females that moved west across the river, most remained in habitat contiguous with the river, and I did not detect any females within the study area of Davis et al. (2009; Figure 2.2). Moreover, I detected minimal northward movement of radio-marked females out of the south Mississippi Delta. Of 110 females included in analyses, < 4% were detected ≥1 times north of Mississippi Highway 82, which divides the south and north Mississippi Delta.

Diurnal Habitat Use

My analysis of diurnal habitat use included 4,307 locations of 110 radio-marked females (n = 22 AHY, n = 88 HY). The final fitted MANOVA model indicated that diurnal habitat use varied among females (Wilks' Lambda = 0.03, $F_{324, 259} = 1.68$, $P < 0.001$), winters (Wilks' Lambda = 0.713, $F_{3, 106} = 14.20$, $P < 0.001$), and time periods within winters (Wilks' Lambda = 0.90, $F_{3, 86} = 3.25$, $P = 0.03$). I failed to detect significant influences of age or any two-way interactions of parameters ($0.13 \leq P \leq 0.79$).

In winter 2010-2011, AGRIC was used more ($P < 0.001$) than MSOIL and OPN-WAT wetlands. I was unable to detect a difference ($P = 0.48$) between use of FOREST and AGRIC in winter 2010-2011. In winter 2011-2012, MSOIL and FOREST were used more ($P < 0.001$) than AGRIC, whereas OPN-WAT was used less ($P < 0.001$) than AGRIC (Table 2.1). Radio-marked females were 3.2 and 1.7 times more ($P < 0.001$) likely to use MSOIL or FOREST than AGRIC, respectively, in winter 2011-2012 than winter 2010-2011. During dry winter 2010-2011, females used of OPN-WAT 4.2 time more ($P < 0.001$) than AGRIC than in winter 2011-2012.

Females used AGRIC more than OPN-WAT but less than FOREST during HUNT2 and POST periods ($P < 0.001$; Figure 2.3). I was unable to detect a difference ($P \geq 0.65$) in use of MSOIL or FOREST compared to AGRIC between time periods; however, OPN-WAT was used 2.3 times more ($P = 0.03$) during POST than during HUNT2 relative to AGRIC.

Nocturnal Habitat Use

I used data from 72 radio-marked female mallards ($n = 7$ AHY, $n = 65$ HY) and 1,133 locations to estimate nocturnal habitat use. The final fitted MANOVA for nocturnal habitat use included influences of female (Wilks' Lambda = 0.01, $F_{207, 142} = 2.2$, $P < 0.001$), winter (Wilks' Lambda = 0.83, $F_{3, 67} = 4.46$, $P = 0.01$), and age (Wilks' Lambda = 0.83, $F_{3, 67} = 4.49$, $P = 0.006$). I did not detect influences of time periods within winters or two way interactions ($0.06 \leq P \leq 0.32$).

Nocturnally, radio-marked females used AGRIC more ($P \leq 0.04$) than FOREST and OPN-WAT in winter 2010-2011; whereas, MSOIL and FOREST were used greater ($P \leq 0.02$) than AGRIC in winter 2011-2012 (Table 2.2). Use of MSOIL and FOREST relative to AGRIC was 2.4 and 4.8 times greater ($P \leq 0.01$) in winter 2011-2012 than the preceding winter, whereas use of OPN-WAT relative to AGRIC was 9.7 times greater ($P = 0.04$) in winter 2010-2011 than 2011-2012.

After hatch year females were less likely ($P \leq 0.02$) to use MSOIL and OPN-WAT nocturnally than AGRIC (Figure 2.4). I was unable to detect a difference ($P = 0.63$) between nocturnal use of FOREST and AGRIC by radio-marked AHY females. Hatch year females were more ($P < 0.001$) likely to use MSOIL but less ($P = 0.02$) likely to use OPN-WAT than AGRIC. Again, I was unable to detect a difference ($P = 0.06$) in

nocturnal habitat use of FOREST and AGRIC among HY females. Hatch year females were 6.8 times more ($P < 0.001$) likely to use MSOIL relative to AGRIC than AHY females. There was no detectable difference ($P = 0.72$) between AHY and HY females in nocturnal use of FOREST relative to AGRIC. Lastly, AHY females were 5.2 times more ($P = 0.01$) likely than HY females to use OPN-WAT relative to AGRIC during nocturnal periods.

Diel Habitat Use

This analysis included 5,440 locations from 110 radio-marked females detected during diurnal and nocturnal periods of both winters combined. Diel habitat use varied by female (Wilks' Lambda = 0.03, $F_{327, 262} = 1.86$, $P < 0.001$). Females used forested wetlands most among all days of both winters (45 ± 2.1% [SE; range 0-97%]), followed by moist-soil wetlands (30 ± 2.1% [range 0-82%]), agriculture (19 ± 1.9% [range 0-83%]), and open water (5 ± 0.7% [range 0-34%]; Figure 2.5).

Discussion

Radio-marked female mallards used habitat complexes during both winters of my study that included flooded croplands, forested and moist-soil wetlands, and permanent open-water water bodies. This finding is consistent with landscape level habitats surrounding large groups of mallards and other dabbling ducks observed by Pearse et al. (2012), while flying winter aerial surveys in the MAV of Mississippi. Pearse et al. (2012) found large groups (>100 individuals) of mallards were associated with landscapes that contained 47% agriculture, 20% forested wetlands, 20% moist-soil wetlands, and 13% permanent water. Small groups (1-99 individuals) were associated

with less agriculture (34%) and moist-soil and more forested wetlands (27%) and permanent water (25%). I did not quantify wetland availability, therefore I am unable to compare proportions of available habitat within ranges used by radio-marked females in my study. However, forested wetlands received greatest use (45%) followed by moist-soil (30%), croplands (19%), and permanent water (5%). Moreover, interesting within- and between-winter patterns of habitat use emerged in my study as described below.

Differential habitat use between winters may have been influenced by weather, landscape habitat characteristics near capture locations, and other unidentified factors. Temperature and precipitation varied markedly between winters of my study. The MAV was unseasonably dry and cold in winter 2010-2011, while mild temperatures and above average rainfall prevailed in winter 2011-2012 (Chapter 1). In winters 2010-2011 and 2011-2012, cumulative rainfall from November through March was nearly 15 cm below and 5.5 cm above the long-term average, respectively. Abundant rainfall in 2011-2012 probably increased natural and managed flooding of forested and moist-soil wetlands. One would surmise that abundant rainfall in winter 2011-2012 would have influenced greater use of flooded agricultural fields by female mallards compared to winter 2010-2011. However, use of flooded agriculture was low in winter 2011-2012 despite increased rainfall. Therefore, other factors, including perhaps decreased abundance of waste agricultural seeds and differences in landscape composition, may better explain habitat use patterns by wintering mallards between winters.

Twice as much rice was grown in the Lower Delta agricultural district of Mississippi in 2010 than 2011 (National Agricultural Statistics Service 2013). Post-harvest, flooded rice fields provide important habitat for a variety of wetland-dependent

birds, including mallards (Elphick and Oring 2003; Manley et al. 2004; Stafford et al. 2006, 2010; Kross et al. 2008*a*; Havens et al. 2010; Marty 2013). Twedt and Nelms (1999) observed 55% of croplands harboring waterfowl and 64% of waterfowl observed were in flooded ricelands. Therefore, a 54% decline in rice production may have had significant influences on patterns of habitat use by female mallards in my study between winters.

Decomposition, germination, and granivory are primary factors influencing significant reductions in abundance of waste agricultural seeds following crop harvests in the MAV and across Tennessee (Stafford et al. 2006, Foster et al. 2010*b*). Together, these exogenous factors can reduce availability of waste seeds to near or below giving-up foraging density of rice and perhaps other seeds for ducks (Stafford et al. 2006, Greer et al. 2010, Foster et al. 2010*a*, Hagy and Kaminski 2012). Therefore, I hypothesize that warm, wet ambient conditions during autumn-winter 2011-2012 compared to the same period the previous year may have decreased waste seed availability in flooded croplands in my study area, perhaps resulting in decreased use of agricultural fields by mallards in winter 2011-2012.

Additionally, the mean capture date of females in winter 2010-2011 was 2 weeks earlier than in winter 2011-2012. Mallards are > 80% paired by February and typically seek isolation following pair formation in scrub-shrub or other densely vegetated wetlands (Heitmeyer 1985, Paulus 1988, Reinecke et al. 1989, Johnson and Rohwer 1998). Because I captured birds later in 2011-2012, greater proportional use of forested habitats could have resulted from mallards selecting those areas for isolation and pair-bond maintenance (Heitmeyer 1988, Johnson and Rohwer 1998). Moreover, pair

formation typically occurs earlier when wetland and food availability is increased in response to flooding, which may have caused earlier and greater use of forested wetlands during the wet and mild winter of 2011-2012 (Fredrickson and Heitmeyer 1988, Heitmeyer 1988, Johnson and Rohwer 1998, Heitmeyer 2006).

Moreover, Cox and Afton (1997) attributed between-winter differences in habitat use by northern pintails (*A. acuta*) to disparities in abundances of agricultural habitats in Louisiana. I witnessed similar patterns in diurnal and nocturnal habitat use by mallards between winters of my study. In winter 2010-2011, I captured 45 of 49 females at Howard Miller and Muscadine WMAs; whereas, I captured 55 of 61 females at Mahannah WMA winter 2011-2012. The landscape surrounding these WMAs is unique. I used USDA Cropland Data Layer (2012) to delineate habitat complexes in a 25-km radius encircling primary mallard capture areas. At Muscadine WMA in winter 2011-2012, land cover was 64 % agriculture and 18 % forested habitats, Howard Miller WMA was surrounded by 46 % agriculture and 35 % forested habitats, and Mahannah WMA was 21 % agriculture and 58 % forested habitats (Table 2.3). Agriculture was the dominant habitat in the landscapes around Muscadine and Howard Miller WMAs for 92% of radio-marked females in winter 2010-2011, perhaps explaining mallards' dominant use of flooded agricultural lands in winter 2010-2011. However, forested habitat dominated surrounding landscape of Mahannah WMA where 90% of radio-marked females were captured in winter 2011-2012. The preponderance of flooded forested wetland around the Mahannah WMA capture site in winter 2011-2012 may have been linked to great use this habitat type that winter when it was flooded, availability of

flooded moist-soil wetlands, and decreased use of flooded croplands as explained previously.

Habitats vary in resource availability, associated predator communities, and survival rates during winter (Chapter 1). Mallards may use habitats differently in response to habitat-specific selective pressures to increase individual probability of survival and meet life-cycle needs during winter. Aside from direct mortality, research has shown that predators also induce nonlethal impacts on prey, such as causing increased alertness or lost foraging time (Madsen and Fox 1995, Laundré et al. 2001). Increased disturbance may create a 'landscape of fear' prompting waterfowl to abandon roost sites or feeding areas for habitats with lower costs of foraging or existence (Fox and Madsen 1997, Van Der Merwe and Brown 2008, Tolon et al. 2009). Additionally, disturbance effects are exacerbated by anthropogenic influences during winter hunting seasons; therefore, habitat use may not be indicative of preferences but use that maximizes survival (Thornburg 1973). For this reason, habitats commonly occurring on inviolate sanctuaries may appear to be important to waterfowl, especially during hunting season. However, habitat use is not mutually exclusive of sanctuary use, but may be part of diel use strategies by wintering mallards in the MAV (Chapter 3).

I observed little use of permanent wetlands, both winters diurnally and nocturnally. Permanent wetlands, including oxbow lakes, rivers, and aquaculture ponds in my study area, generally with depths > 1 m, provide little accessible food to mallards. Most permanent wetlands exceed the mean depth (≤ 16 cm) seemingly preferred by dabbling ducks feeding in moist-soil wetlands (Hagy and Kaminski 2012). However, permanent wetlands can provide important roosting or loafing areas to ducks especially

during cold or drought periods during winter (Jorde et al. 1984, Christopher et al. 1988). Moreover, because of mallard's gregarious nature during the non-breeding season (Owen and Black 1990, Legagneux et al. 2009), they may be attracted to permanent water habitats by the presence of con- or heterospecific waterfowl (Elmberg et al. 1997, Thomson et al. 2003). Adult females were more likely to use permanent water than HY females at night, which likely was caused by the majority of AHY females being captured during cold winter 2010-2011. Minimum daily temperatures were below freezing 47 days from December-February in winter 2010-2011, while only 20 sub-zero days occurred in winter 2011-2012 (Figure 2.6). Moreover, there were 4 days from December-February that the daily maximum temperature did not exceed 0° C in winter 2010-2011, likely forcing mallards to use unfrozen permanent waters (Figure 2.7; Jorde et al. 1984). I surmise the lack of age difference in diurnal use of permanent water is because daytime high temperatures were rarely below freezing, thus allowing females to utilize other habitats.

Although mallards radio-marked in northeast Louisiana and Mississippi overlapped little in space use (Davis et al. 2009; Figure 2.2), females used habitats similarly in respective regions. For example, radio-marked mallards in both states spent more time diurnally in forested wetlands than any other habitat. Nonetheless, moist-soil habitats were important to mallards in my study area, as use averaged between 22-31% diurnally compared to ≤ 7 % in Louisiana (Davis et al. 2009). Similarly, radio-marked mallards made greatest nocturnal use of forested wetlands in Louisiana and Arkansas (Davis et al. 2009); whereas, I observed greatest use of moist-soil wetlands at night during both winters. I attribute these discrepancies in habitat use to differences in

landscape composition and likely habitat availability between the two states, but future analyses incorporating estimates of habitat availability are needed to evaluate this hypothesis (Table 2.4; Davis et al. 2009).

A goal of my study was to identify patterns of habitat use by radio-marked mallards and compare patterns with previous research on this species in the MAV. I found that habitat use patterns by mallards in my study deviated from those detected by aerial surveys during the mid-late 1980s (Dell et al. 1987, Reinecke et al. 1992). Dell et al. (1987) reported great densities and occurrence of mallards in flooded soybean or other agricultural habitats, whereas low densities were encountered in forested habitats. Reinecke et al. (1992) also reported greatest use of flooded agricultural lands (53-85%) by mallards but little use of forested (3-11%) and moist-soil (3-29%) habitats during winters 1987-1990. Therefore, two historical studies using aerial transects identified agriculture and open wetlands as most important, while two contemporary studies using radio-marked individuals identified forested habitats as important diurnally (Dell et al. 1987, Reinecke et al. 1992, Davis et al. 2009, this study). These discrepancies in habitat use probably were related to decreased visibility of birds in densely vegetated wetlands (Pearse et al. 2008, Davis et al. 2009). Pearse et al. (2008) experimented with detection rates of mallards and found that small simulated groups of ducks (< 15 decoys) were detected at greater rates in forested than open wetlands, whereas detection of larger groups of (15-100 decoys) was greater in open wetlands. Smith et al. (1995) cautioned that comparisons of waterfowl abundance should be restricted to years when ≥ 70% of the population is expected to occur in open wetlands. However, based on results from Davis et al. (2009) and my study, mallard populations in the MAV may never achieve

≥70% occurrence in open wetlands. Therefore, studies using radio-telemetered birds provided reliable estimates of habitat use by mallards because detection rates from aerial surveys are biased in some habitats. Trends in mallard habitat use between historic and contemporary studies can likely be attributed to methodological differences (Davis et al. 2009), although changes in habitat composition and availability are possible.

In California, the amount of flooded rice increased substantially between the mid-1980s and late 1990s (Fleskes et al. 2005*b*). Farmers increasingly flooded rice fields post-harvest to expedite decomposition of rice straw following the California Rice Straw Burning Reduction Act of 1991 (Hill et al. 1999, Fleskes et al. 2007). Fleskes et al. (2005*a*) reported increased use of agricultural fields by female mallards from winters 1987-1990 (pre-burn ban) to 1998-2000 (post-ban) following a 73-84% increase in flooded agricultural habitats, primarily ricelands.

I speculate that changes in land use and agricultural practices in the MAV since the 1980s contributed somewhat to disparity between contemporary and previous patterns of habitat use by mallards. In the Lower Delta agricultural district of Mississippi, corn production increased 6,300% between 1988 and 2010, primarily replacing cotton production, which decreased 57 % (USDA National Agricultural Statistics Service 2013; Figure 2.8). The decline in cotton production from 1988 to 2010 in the south Mississippi Delta would not be impactful to waterfowl because this cropland provides little benefit to wintering waterfowl (Twedt and Nelms 1999), with the exception of rare use by northern pintails or geese (tribe Anserini) when flooded (Ballard 1993, Fleskes et al. 2003, Taft and Elphick 2007). In contrast, corn is valuable waterfowl forage for mallards and other waterfowl on the wintering grounds and elsewhere (Smith et al. 1989, Twedt and Nelms

1999, Foster et al. 2010*b*) with metabolizable energy greater than most other cereal grains (Petrie et al. 1998, Kaminski et al. 2003, LMVJV 2007). However, early harvest, post-harvest practices (e.g., disking), and prolonged flooding prior to waterfowl arrival can significantly limit abundance of residual corn to waterfowl in the MAV and elsewhere (Baldassarre et al. 1983, Baldassarre and Bolen 1984, Warner et al. 1985, Foster et al. 2010*a*,*b*). Moreover, post-harvested corn fields are rarely flooded in the MAV except where managed expressly for waterfowl hunting (Pearse 2007). Pearse (2007) reported that flooded corn represented <1% of flooded habitat available to wintering waterfowl during aerial surveys conducted January 2003-2005.

Evidence from Dell et al. (1987) and Pearse (2007) indicated that proportional to other flooded habitats, inundated soybean fields may be less common today in the MAV of Mississippi (12%) than historically prevalent in northeastern Louisiana (35%). The decline in flooded soybean likely resulted from farmers retiring flood prone croplands and enrolling them in Natural Resources Conservation Service (NRCS) Farm Bill programs such as the WRP. For example, from 1990-2005, 62,000 ha of cropland have been restored in Mississippi through the WRP (King et al. 2006). Primary management techniques of WRP restoration include afforestation of hard mast and other facultative wetland tree species and hydrologic restoration including formation of moist-soil impoundments (King et al. 2006, Fleming et al. 2012). Davis et al. (2009) reported from 3-24% of locations by radio-marked female mallards occurred on WRP or similar afforested habitats in Louisiana, whereas I recorded 18% of locations on such habitats in Mississippi (unpublished data). Therefore, retirement of marginal soybean fields and

replacement with bottomland hardwood species or moist-soil impoundments may explain greater use of forested and moist-soil wetlands than flooded croplands in my study.

Availability and quality of habitats available to wintering waterfowl are fundamental to birds' survival, ability to select and retain mates, and other important biological events and outcomes (Heitmeyer and Fredrickson 1981, Heitmeyer 1985, Chapter 1). Therefore, I argue importance to develop rigorous means to estimate accurately fall-winter wetland habitat availability in dynamic landscapes like the MAV that change annually with agricultural commodity prices (Chavas et al. 1983) and winter rainfall events (Taft et al. 2004). Perhaps aerial surveys with manned or unmanned aircraft, using videography to develop predictors of inundated crop- and other lands, could be used to estimate composition and extent of available wetlands in the MAV (Farrell 2013). Indeed, such a technique would advance knowledge accrued from earlier studies of waterfowl habitat use in this region during winter. Moreover, management recommendations based on current knowledge of habitat use patterns by non-breeding mallards in the MAV may be misleading, because habitat use by mallards is not linked to robust estimates of habitat availability. This limitation hampers determination of habitat selection (i.e., habitats use greater than relative availability; Kaminski and Weller 1992, Cooper and Millspaugh 2001) and comparison between study areas composed of different landscapes and intrinsic resources. In addition, future research should calculate habitat or resource selection at multiple scales to identify complexes of habitat that are used and selected by mallards wintering in the MAV and elsewhere (Wiens 1973, 1976; Johnson 1980; Pearse et al. 2012). Research should also study cross-seasonal effects, specifically examining how fall migration distance, wintering locations, and resource use

relate to subsequent survival, breeding propensity and success, and recruitment, especially in relation to climate landscape changes in North America (e.g., Kaminski 1985). Refinements in satellite-telemetry and other technology may enable future researchers to accomplish these needs.

Management Implications

I quantified diel habitat use of female mallards to identify overall important habitats used during winter apart from localized or temporal patterns found through diurnal or nocturnal analyses. However, I recognize that diel habitat use may be biased due to disproportionate numbers of daytime and nighttime locations of females. For example, 64% of diurnal and 91% of nocturnal locations were collected in winter 2011-2012, and 79% of locations in diel analysis were from daytime periods. Nonetheless, nearly half (45%) of all female locations were in forested wetlands, and individual females were detected up to 97% of the time in forested wetlands. Forested wetlands were also most important to wintering radio-marked mallards in the MAV of northeastern Louisiana and southeastern Arkansas (Davis et al. 2009). Therefore, continued retirement, restoration, and afforestation of farmlands through the WRP and other Farm Bill programs are important to providing forested wetlands for wintering mallard and other wildlife in the MAV (Schoenholtz et al. 2001, Fredrickson et al. 2005). Contrary to Twedt et al. (2006), WRP contracts need not prioritize areas that create > 2,000 ha of forest core to benefit mallards. Managers may instead focus on the agriculturally dominant landscapes and subsequently manage areas in which bottomland hardwoods are missing or underrepresented, thus creating complexes of wetland habitats (Fredrickson and Heitmeyer 1988, Fredrickson and Reid 1988, Fleming et al. 2012, Pearse et al. 2012).

Aside from afforestation, WRP and other conservation program contracts should continue restoration of hydrology and management of moist-soil plant communities (King et al. 2006, Kross et al. 2008*b*, Fleming 2010, Fleming et al. 2012, Schummer et al. 2012). Moist-soil wetlands were the second most important wetland habitat, accounting for 30% of radio-marked mallard locations and up to 82% of use for some females. Restoration and management of moist-soil plant and forested wetlands increase habitat diversity amidst a dominantly agrarian landscape in the MAV. Moreover, active management with early or late drawdown should be applied to seasonal emergent wetlands to improve forage quality and habitat use by mallards and other wintering waterfowl (Kross et al. 2008*b*, Fleming 2010, Fleming et al. 2012).

Flooded agricultural habitats accounted for 19% of female locations and were especially important during winter 2010-2011, likely because of cold temperatures. Agriculture will likely remain the dominant land use of the MAV. I suggest use of various manipulative and flooding techniques that have been evaluated in relation to waterfowl use of harvested croplands and wetlands in the MAV (e.g., Kross et al. 2008*a*, Havens et al. 2009, Hagy and Kaminski 2012, Marty 2013); these practices benefit wintering waterfowl and waterbirds (Elphick and Oring 2003, Manley et al. 2004, Stafford et al. 2010, Pearse et al. 2012, Marty 2013). Given that other croplands are super-abundant on the landscape, I also advocate the capture of rainwater on post-harvested fields to provide added habitat and improve water quality (Manley et al. 2004, 2009). Fields that are near zero grade capture rainfall or can be artificially pumped with minimal cost during winter (Twedt and Nelms 1999). Rice fields are especially easy to flood, rice seed decomposes slower than other agricultural seeds when flooded (e.g.,

soybeans; Stafford et al. 2006), and landowners incur agronomic benefits from winter flooded fields (Uihlein 2000, Elphick and Oring 2003, Manley et al. 2004). Moreover, field maintenance costs can be recuperated by establishing waterfowl hunting opportunities to lessees (Yarrow and Yarrow 1999, Jones et al. 2004).

Use of permanent wetlands was negligible by radio-marked females. However, during times of severe drought or cold weather these wetlands, such as .aquaculture ponds, rivers, and oxbow lakes, are important. These ponds and wetlands typically are too deep for foraging dabbling ducks and not easily managed hydrologically. Therefore, active management should focus on croplands, forested wetlands, and moist-soil plant communities, where feasible.

Table 2.1 Diurnal proportional use of habitats by winter.

Winter	n [a]	# of loc[b]	AGRIC[c]		M-SOIL[c]		FOREST[c]		OPN-WAT[c]	
			$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
2010-2011	49	1,566	0.325	0.027	0.219[d]	0.027	0.399	0.033	0.057[d]	0.01
2011-2012	61	2,741	0.108	0.016	0.311[d]	0.023	0.541[d]	0.022	0.04[d]	0.006

[a] Number of radio-marked females tracked during each winter.

[b] Number of individual locations during each winter.

[c] AGRIC = flooded agriculture, M-SOIL = fallow agriculture and seasonal emergent wetlands, FOREST = forested and scrub-shrub wetlands, OPN-WAT = rivers, aquaculture facilities, and lakes.

[d] Transformed values of proportional use of habitat differed significantly ($P \leq 0.05$) from transformed values of AGRIC within a row.

For female mallards radio-marked at three Wildlife Management Areas in the south Mississippi Alluvial Valley in Mississippi during in winters 2010-2011 and 2011-2012.

Table 2.2 Nocturnal proportional use of habitats by winter.

Winter	n [a]	# of Loc[b]	AGRIC[c]		M-SOIL[c]		FOREST[c]		OPN-WAT[c]	
			$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
2010-2011	17	104	0.3	0.082	0.414	0.106	0.222[d]	0.089	0.065[d]	0.041
2011-2012	55	1,029	0.077	0.018	0.588[d]	0.03	0.282[d]	0.026	0.053	0.012

[a] Number of radio-marked females tracked during each winter.

[b] Number of individual locations during each winter.

[c] AGRIC = flooded agriculture, M-SOIL = fallow agriculture and seasonal emergent wetlands, FOREST = forested and scrub-shrub wetlands, OPN-WAT = rivers, aquaculture facilities, and lakes.

[d] Transformed values of proportional use of habitat differed significantly ($P \leq 0.05$) from transformed values of AGRIC within a row.

For female mallards radio-marked at three Wildlife Management Areas in the south Mississippi Alluvial Valley in Mississippi during in winters 2010-2011 and 2011-2012.

Table 2.3 Proportions of habitats within a 25-km radius surrounding Wildlife Management Areas.

Habitat[a]	Muscadine Farms	Howard Miller	Mahannah
NON-HAB	0.06	0.03	0.05
AGRIC	0.64	0.46	0.21
M-SOIL	0.05	0.07	0.07
FOREST	0.18	0.35	0.58
OPN-WAT	0.07	0.08	0.09

[a] NON-HAB = developed and industrial non habitat, AGRIC = agriculture, M-SOIL = fallow agriculture and seasonal emergent vegetation, FOREST = forested and scrub-shrub habitats, OPN-WAT = rivers, aquaculture facilities, and lakes.

Wildlife Management Areas in the Mississippi Alluvial Valley in Mississippi, where female mallards were captured and radio-marked during winters 2010-2011 and 2011-2012.

Table 2.4 Differences in study area composition between my study and Davis et al. (2009).

Habitat[a]	My Study	Davis et al. 2009
NON-HAB	0.06	0.06
AGRIC	0.41	0.16
M-SOIL	0.11	0.1
FOREST	0.38	0.66
OPN-WAT	0.04	0.02

[a] NON-HAB = developed and industrial non habitat, AGRIC = flooded agriculture, M-SOIL = fallow agriculture and seasonal emergent wetlands, FOREST = forested and scrub-shrub wetlands, OPN-WAT = rivers, aquaculture facilities, and lakes.

Within the Mississippi Alluvial Valley of Mississippi in winters 2010-2012 and Louisiana in winters 2006-2006, respectively.

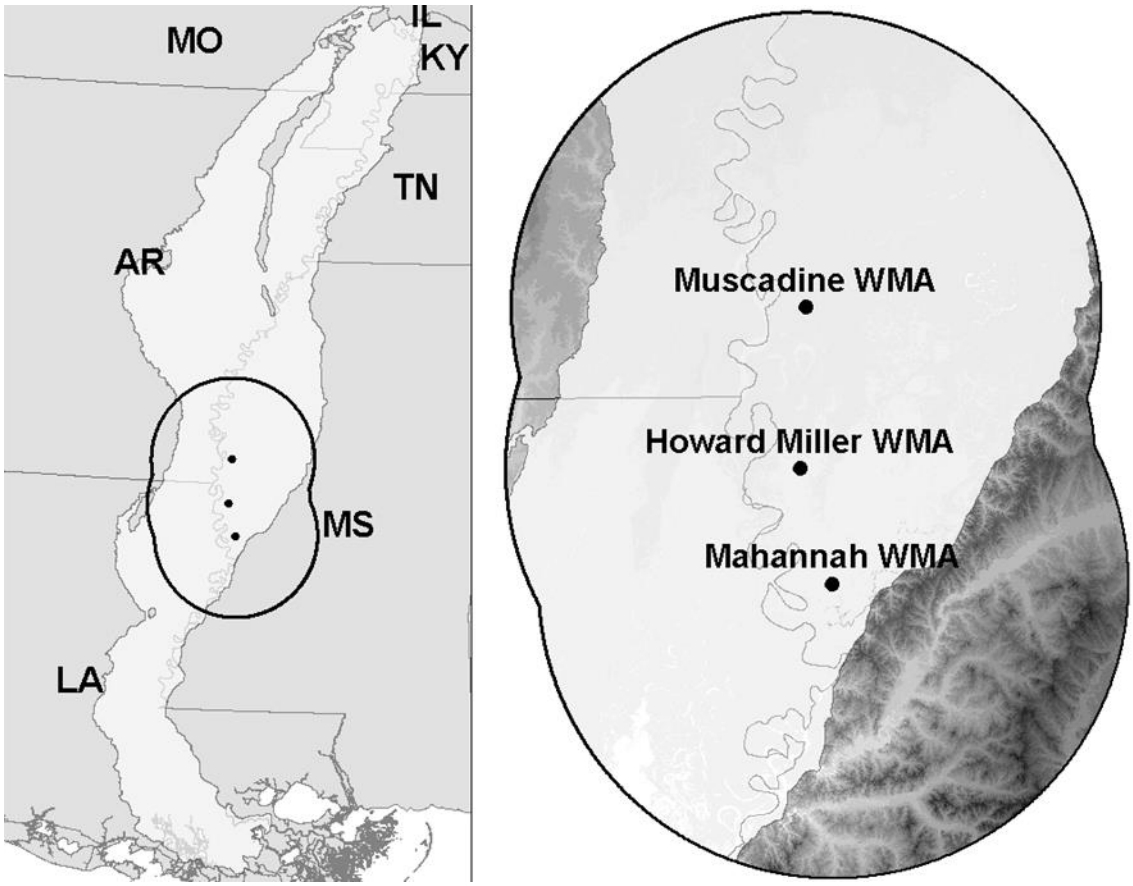

Figure 2.1 Locations where female mallards were captured, radio-marked and tracked.

Capture locations (black dots) on Wildlife Management Areas (WMA) in the Mississippi portion of the Mississippi Alluvial Valley and 80 km surrounding search area (black circle) during winters 2010-2012.

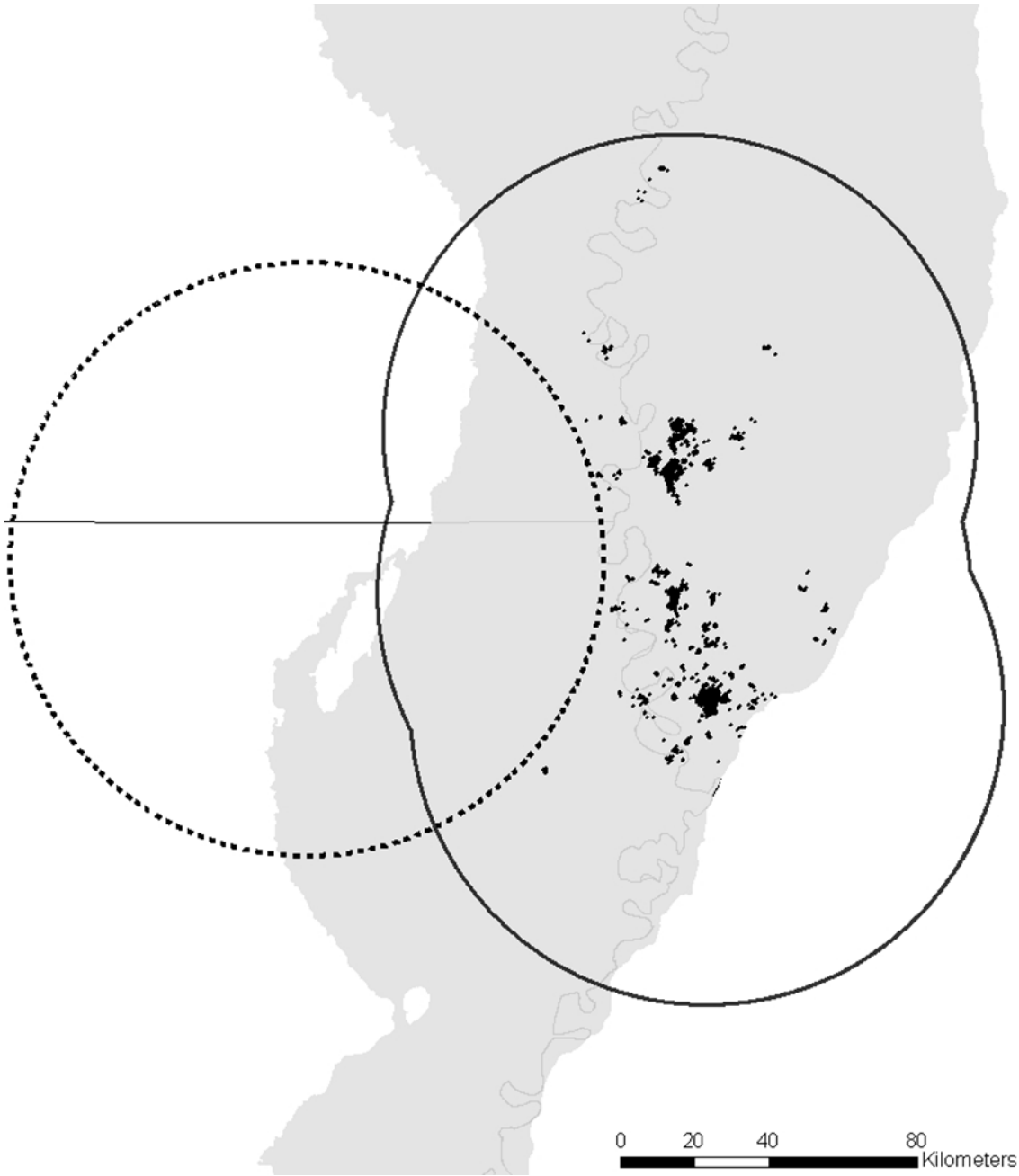

Figure 2.2 Study-area overlap between my study area (solid circle) and locations (black dots) of radio-marked female mallards to that of Davis et al. (2009; broken circle) within the south Mississippi Alluvial Valley.

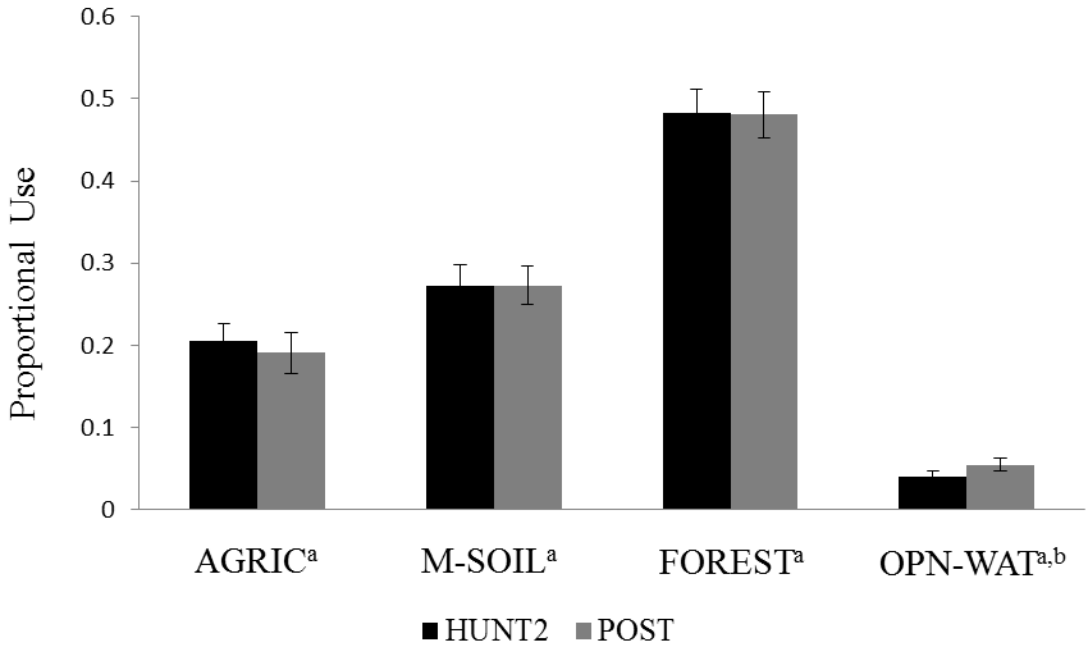

Figure 2.3 Diurnal proportional use of habitats by period.

[a] AGRIC = flooded agriculture, M-SOIL = fallow agriculture and seasonal emergent wetlands, FOREST = forested and scrub-shrub wetlands, OPN-WAT = rivers, aquaculture facilities, and lakes.

[b] Transformed values of proportional use within habitat differed significantly ($P \leq 0.05$) between HUNT2 and POST.

For female mallards radio-marked at three Wildlife Management Areas in the south Mississippi Alluvial Valley in Mississippi by time period for combined winters 2010-2011 and 2011-2012.

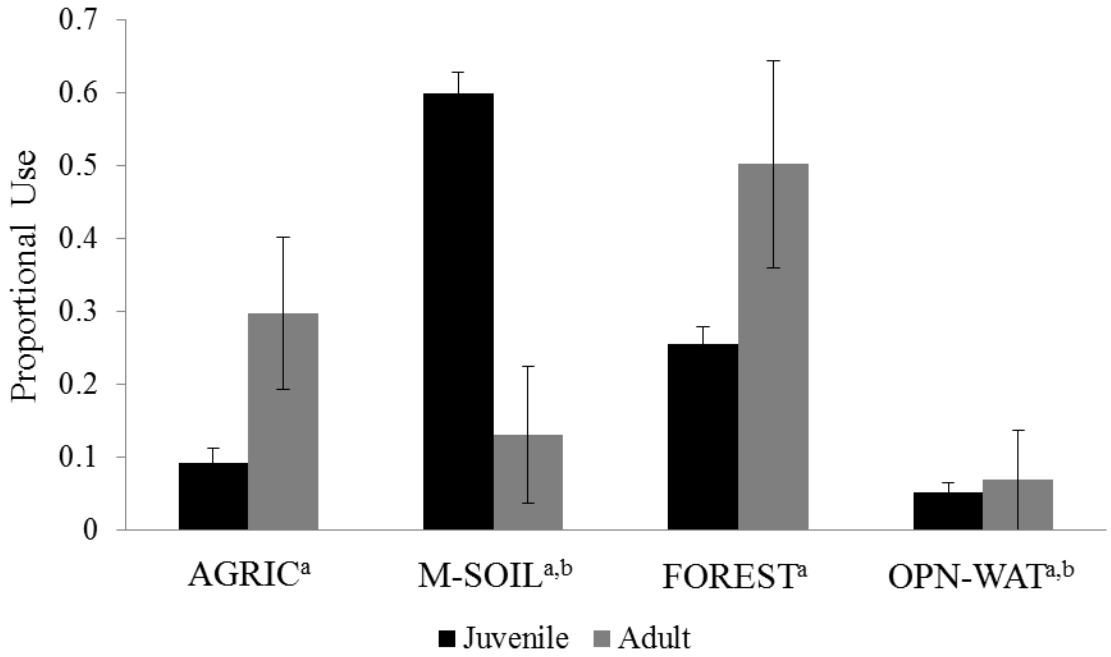

Figure 2.4 Nocturnal proportional use of habitats by age.

[a] AGRIC = flooded agriculture, M-SOIL = fallow agriculture and seasonal emergent wetlands, FOREST = forested and scrub-shrub wetlands, OPN-WAT = rivers, aquaculture facilities, and lakes.

[b] Transformed values of proportional use within habitat differed significantly ($P \leq 0.05$) between juveniles and adults.

For juvenile and adult female mallards captured and radio-marked at three Wildlife Management Areas in the south Mississippi Alluvial Valley in Mississippi in combined winters 2010-2011 and 2011-2012.

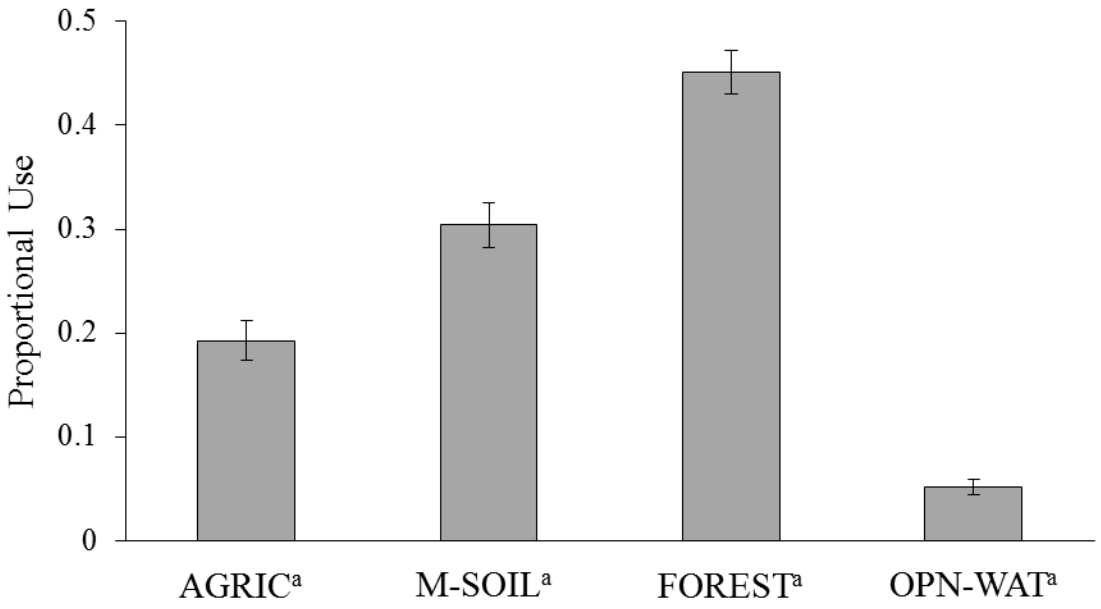

Figure 2.5 Diel proportional use of habitats.

[a] AGRIC = flooded agriculture, M-SOIL = fallow agriculture and seasonal emergent wetlands, FOREST = forested and scrub-shrub wetlands, OPN-WAT = rivers, aquaculture facilities, and lakes.

For female mallards captured and radio-marked at three Wildlife Management Areas in the south Mississippi Alluvial Valley in Mississippi in combined winters 2010-2011 and 2011-2012.

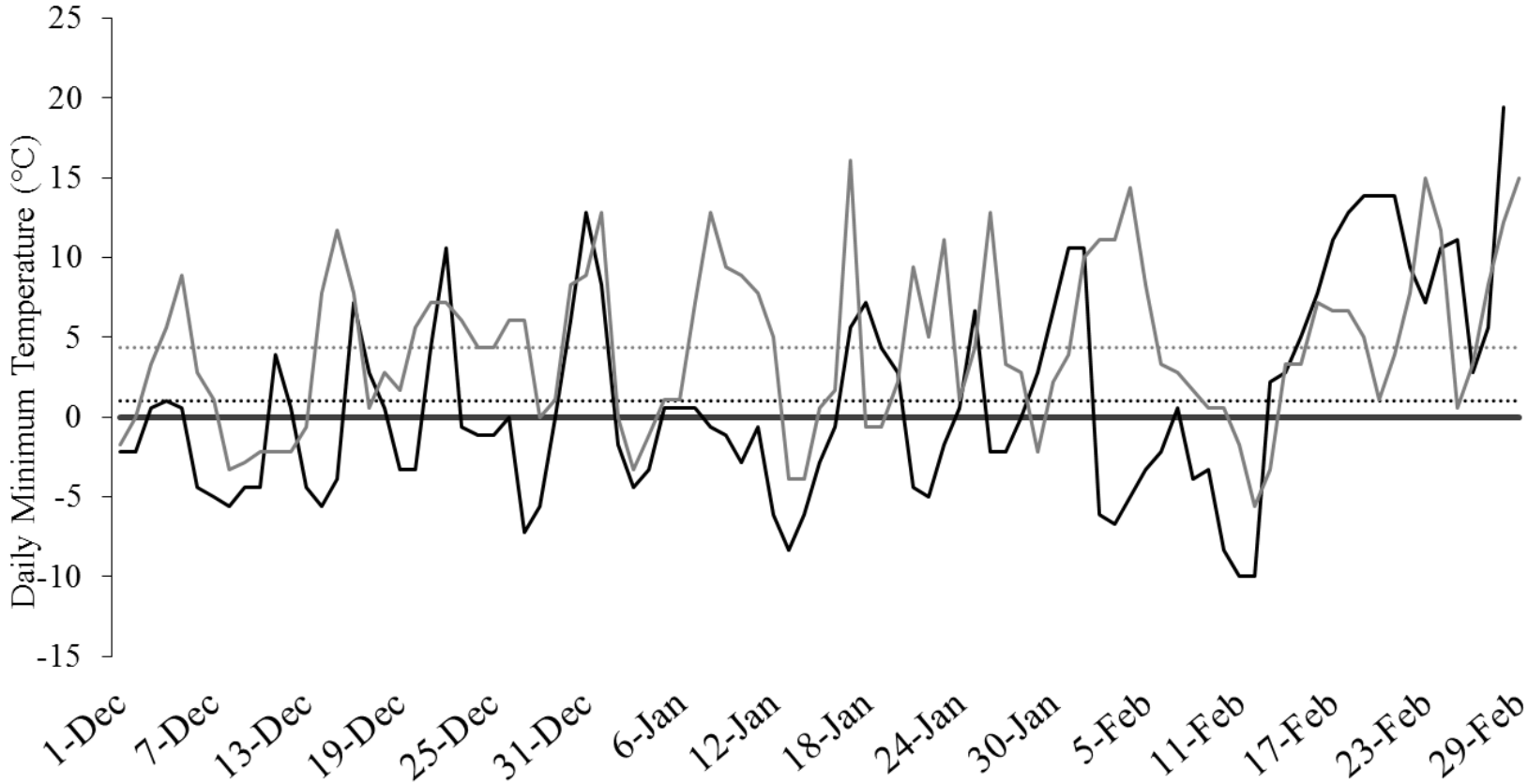

Figure 2.6 Daily minimum temperature for December-February.

For winters 2010-2011 (thin black line) and 2011-2012 (thin gray line) in Rolling Fork, Mississippi near the center of my study area. Dotted lines indicate average minimum temperature over the 3 month period and heavy solid black line indicates freezing (0° C).

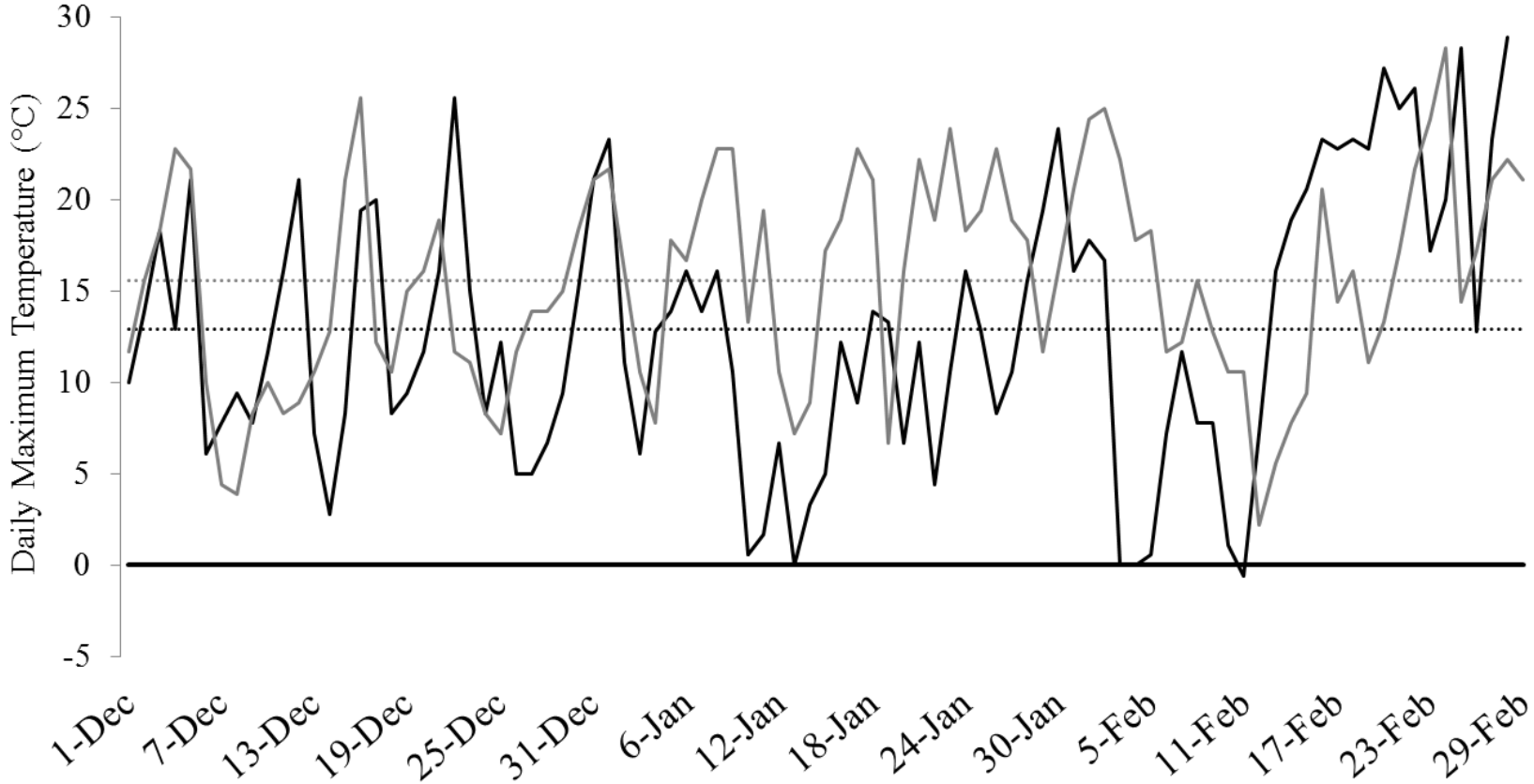

Figure 2.7 Daily maximum temperature for December-February.

For winters 2010-2011 (thin black line) and 2011-2012 (thin gray line) in Rolling Fork, Mississippi near the center of my study area. Dotted lines indicate average minimum temperature over the 3 month period and heavy solid black line indicates freezing (0° C).

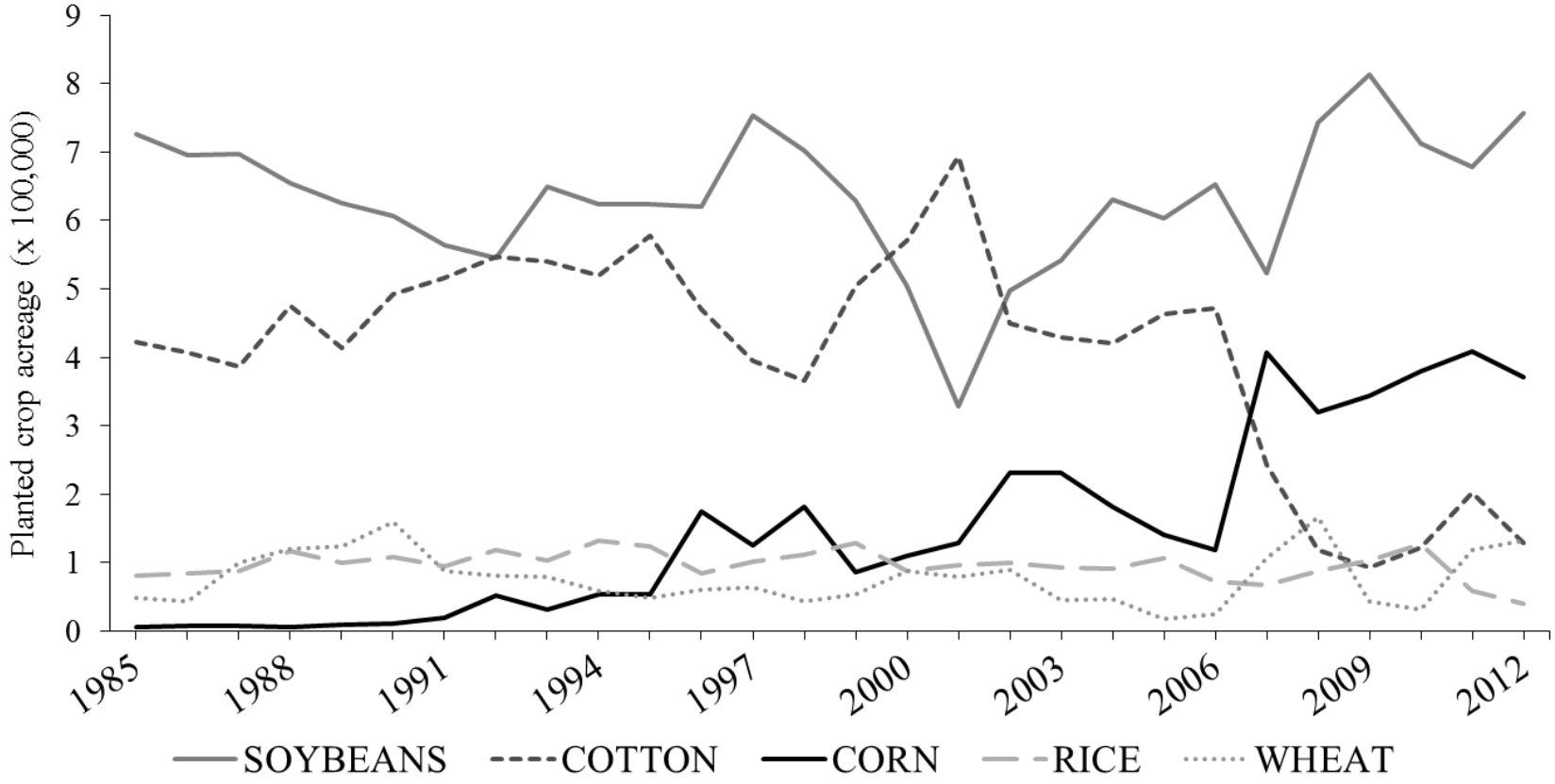

Figure 2.8 Planted acreage (in 100,000s) of the 5 most frequently grown crops between 1985 and 2012 in the Lower Delta agricultural district in Mississippi.

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CHAPTER III

SPATIOTEMPORAL USE OF WILDLIFE MANAGEMENT AREAS HUNTED 2- AND 4-DAYS PER WEEK BY FEMALE MALLARDS

The North American Waterfowl Management Plan (NAWMP) is a legacy conservation document recognized by waterfowl scientists and managers worldwide. The success of the NAWMP is rooted in its defensible scientific foundation and ever evolving goals for conserving waterfowl and their habitats continentally in perpetuity. Revised in 2012, the NAWMP prioritized three specific goals to advance waterfowl stewardship, one of which advocated recruitment of waterfowl hunters and other conservationists to embrace and fiscally support waterfowl and wetlands conservation throughout North America (NAWMP Revision 2012:2). The Human Dimensions Working Group of the NAWMP was formed and tasked with addressing strategies for recruiting and retaining waterfowl hunters and other conservationists (NAWMP Revision 2012:31). Prior research investigated motivations for involvement or exodus of hunters from pursuit of waterfowl (Miller and Hay 1981, Enck et al. 1993). Myriad personal reasons surfaced for reduced or relinquished participation in waterfowl hunting but chief among them was having nowhere to hunt.

Federal and state conservation areas often are managed to meet site- and game species-specific objectives, including providing opportunity for hunting waterfowl (Miller and Hay 1981, St. James et al. 2013). Therefore, responsible management of

these lands must achieve balance between providing quality public hunting opportunity and meeting biological needs of waterfowl (St. James et al. 2013). Naturally inherent in providing reasonable public hunting opportunity is the consequence of waterfowl disturbance (Thornburg 1973, Madsen and Fox 1995, Fox and Madsen 1997, Madsen 1998, St. James et al. 2013). Excessive hunting on public or private lands may lead to reduced harvest opportunities because birds abandon the area, which could ultimately deflate experiences for hunters (Thornburg 1973, Fox and Madsen 1997, Knapton et al. 2000, Bregnballe and Madsen 2004, Brochet et al. 2009, St. James 2011). On the other extreme, public or private lands may restrict hunting temporally (e.g. 1-day/wk.), thus reducing opportunity afield in order to increase harvest opportunities and hunter satisfaction (St. James et al. 2013). Ultimately, a balance between providing opportunities for hunting and harvest must be struck to sustain hunter satisfaction.

In a pursuit of such balance, several strategies have proven effective in sustaining waterfowl abundance amid hunting activities: 1) temporal regulations, such as restricting hunting to varying numbers of days/week or ceasing hunting at noon (Fox and Madsen 1997, Bregnballe and Madsen 2004, St. James et al. 2013) 2) provision of inviolate sanctuaries (Fox and Madsen 1997, Madsen 1998, Evans and Day 2002, Mathevet and Tamiser 2002, Brochet et al. 2009), and 3) limiting hunter density, such as the number of hunters per party or the number of parties allowed to access the area (Fox and Madsen 1997, St James 2011). Most often, multiple strategies are used to promote positive or desired outcomes of hunter opportunity, satisfaction, and waterfowl abundance (St. James 2011).

Recently, St James (2011) compared waterfowl abundance and hunter harvest on two Wildlife Management Areas (WMA) operated by the Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP) in western Mississippi. Each WMA contained two divisions of similar size and habitat composition randomly assigned to be hunted either 2- or 4 days per week. St. James et al. (2013) detected no difference in waterfowl abundance between hunt frequency treatments. Moreover, mean harvest of mallard (*Anas platyrhynchos*), northern shoveler (*A. clypeata*), and green-winged teal (*A. carolinensis*) were similar between experimental levels of hunt frequency (St. James 2011). Therefore, more conservative hunting regulations neither increased duck abundance nor harvest on WMAs. St. James (2011) and St. James et al. (2013) recommend that MDWFP establish 4-hunt days per week as a method to increase public hunting opportunity without negatively affecting waterfowl numbers and harvest on the WMA.

A second approach to increase waterfowl abundance on hunted areas is to cease hunting at midday to encourage re-colonization in afternoons (Fox and Madsen 1997, St. James 2011). This approach theoretically also benefits waterfowl by allowing waterfowl to compensate for foraging time possibly lost due to hunter disturbance (Madsen and Fox 1995, Fox and Madsen1997, McNeil et al. 1992). Dooley et al. (2010) reported that radio-marked mallards subject to simulated direct disturbance (i.e., legally fired upon but not killed by hunters) had low return rates per day (23%) to disturbed areas. However, individual ducks may be subject to disparate types or intensities of disturbance which may confound their return rates (Fox and Madsen 1997). Consequently, return rates or elapsed time of return may differ for ducks directly shot at or those that were disturbed by

non-hunting factors (i.e., natural predator or automobile; Bélanger and Bédard 1989, Knapton et al. 2000, Pease et al. 2005).

Another strategy to balance hunting opportunity and waterfowl use is to locate reserves or sanctuaries (e.g., non-hunted national wildlife refuges [NWRs]) adjacent to or within hunted areas to provide refugia for waterfowl (Madsen and Fox 1997, Madsen 1998, Bregnballe and Madsen 2004, St. James 2011, Roy et al. 2013). St. James et al. (2013) monitored duck abundance within-WMA sanctuaries during two hunting seasons. They found no difference in waterfowl abundance in sanctuary locations when only half of the WMA was hunted, all of it was hunted, or the WMA was closed, although they noted that bird abundance increased 30% in the sanctuary as morning progressed. Similarly, Dooley et al. (2010) reported that radio-marked mallards flew 3-5 km following shooting disturbance. These studies suggest that proximate sanctuaries may be too close to act as refugia to waterfowl disturbed on a WMA. However, there are likely several factors that influence use of refuges including local and adjacent food sources, size of refugia, and distance to other suitable habitats (Madsen and Fox 1995, Fox and Madsen 1997, Brown and Kotler 2004).

St. James' (2011) study was novel and informative, but questions remain about spatial and temporal use of WMAs before, during, and after hunting seasons by waterfowl, notably mallards as they are coveted by waterfowl hunters throughout North America (Anderson and Burnham 1976, Bellrose 1976, Smith and Reynolds 1992, St. James 2011). Moreover, St. James (2011) found that hunters' perceived quality of a hunt increased with total body mass of harvest, suggesting harvest of large-sized ducks (e.g., mallards) increased hunter satisfaction. St. James (2011) was precluded from obtaining

data on duck abundance when the WMA was hunted, therefore she could not assess if waterfowl remained in non-hunted portions of the WMA or redistributed to other locations. Despite contemporary and novel approaches to understanding waterfowl use of sanctuaries and hunted areas, investigations that specifically address individual waterfowl use of hunted, sanctuary, and adjacent private lands are lacking but are needed to guide temporal and spatial management of waterfowl hunting on WMAs in Mississippi.

The unique division of hunting regimes implemented at two MDWFP WMAs allowed me to address additional questions about spatiotemporal distribution of mallards at these locales (St. James et al. 2013). Therefore, I quantified use of WMAs (i.e., sanctuary and 2- or 4-day/week hunted areas), private lands, and nearby National Wildlife Refuges (NWR) by radio-marked female mallards in relation to 1) closed periods within hunting season, 2) open waterfowl hunting periods but closed on WMAs, 3) half of WMA units open for waterfowl hunting, or 3) all WMA units open to hunting. My approach was complementary and concurrent to St. James et al.'s (2013), because I could assess use of WMAs and other public or private lands by individually-marked birds exposed to different hunt regimes.

To further investigate these patterns, I used a remote data-collection station at Muscadine WMA to quantify proportion of time radio-marked birds spent on the WMA and identify hourly patterns of radio-marked mallards subjected to various hunt regimes. Understanding temporal and spatial use patterns of habitats by mallards is important for hunting and sanctuary management and increasing overall knowledge of ecology of mallards on wintering areas. My ultimate goal is to provide useful information to

wetland managers regarding spatial and temporal sanctuary requirements of mallards which identify hunting regimes that satisfy opportunity and quality experiences of the hunting public.

Study Area

I captured mallards at three state-managed Wildlife Management Areas (WMAs) in the southern portion of the Mississippi MAV (Figure 3.1): 1) Howard Miller WMA is a 971 ha seasonally flooded complex near Rolling Fork, Mississippi (32°49'48.93" N, 90°58'51.61" W), which is annually planted to rice and soybean but also contains seasonal emergent vegetation supplemented with plantings of corn and Japanese millet; 2) Mahannah WMA, near Vicksburg, Mississippi (32°32'54.95" N, 90°52'14.08" W), is a 5,100 ha complex with expansive bottomland hardwoods, scrub-shrub, seasonal emergent vegetation, and rice and soybean. Approximately 80% of Mahannah WMA is seasonally and naturally flooded annually, and the remaining area is managed for upland species. primarily white-tailed deer (*Odocoileus virginianus*); and 3) Muscadine Farms WMA, near Avon, Mississippi (33°13'29.32" N, 90°59'01.51" W), is a 607 ha retired catfish pond complex owned by the U.S Army Corps of Engineers. The complex is managed for waterfowl through seasonal vegetation manipulation, supplemental plantings of corn and Japanese millet, and strategic fall-winter flooding of impoundments.

My technicians and I tracked female mallards in all areas within 80 km of trapping sites, which included portions of northeast Louisiana and southeast Arkansas (Figure 3.1; Cox and Afton 1997, Davis et al. 2009). In addition to trapping locations, the tracking area included publicly owned (Mississippi Department of Wildlife, Fisheries,

and Parks [MDWFP]) and managed WMAs (i.e., Charlie Capps, Lake George, Leroy Percy, Shipland, Sky Lake, Stoneville, Sunflower, and Twin Oaks WMAs). State managed lands in the study area outside of Mississippi included Big Lake and Buckhorn WMAs in Louisiana and Casey Jones and Seven Devils Lake WMAs in Arkansas. Federal lands included Dahomey, Hillside, Holt Collier, Mathews Brake, Morgan Brake, Panther Swamp, Theodore Roosevelt, and Yazoo National Wildlife Refuges (NWR) in Mississippi, Delta National Forest in Mississippi, Handy Brake and Tensas River NWRs in Louisiana, and Overflow NWR in Arkansas. Additional environmental details of the MAV are in the literature (e.g., Reinecke et al. 1989, Baldassarre and Bolen 2006).

Methods

Mallard Capture and Tracking

I captured female mallards from early November 2010-2011 through late January 2011-2012 on WMAs using swim in traps modified from those described by Hunt and Dahlka (1953) or rocket nets fired from portable platforms (Dill and Thornberry 1950, Cox and Afton 1994). Capture sites were baited with rice, soybean, sweet potato, or corn and were located throughout the WMAs prior to hunting season. Ten to 12 days prior to hunting season, all traps and remaining bait in hunting units were removed. Traps were relocated to sanctuaries as distantly as possible from waterfowl hunting areas to eliminate possible effects of bait on duck distribution and hunting.

I designated captured females as juvenile (hatch year; HY) or adult birds (after hatch year; AHY) according to wing plumage characteristics (Carney 1992). I banded each female with a United States Fish and Wildlife Service aluminum leg band and attached a 23 g VHF backpack transmitter (Dwyer 1972). Transmitters had a pulse of 55

beats per minute, had a life expectancy of 150 days, and were equipped with a mercury type mortality sensor that doubled the pulse rate when transmitters were motionless for ≥8 hours. Transmitters weighed 2.1% (± 0.02% [SE], n = 113) of mean female body mass on date of capture. Transmitter weight < 5% of a bird's body mass are thought to prevent physiological or behavioral burden on the individual (Cochran 1980, Casper 2009). I held females 4-6 hours after morning capture and 12-18 hours (overnight) when captured in the afternoon to allow adjustment to the transmitter and ensure proper fit (Davis et al. 2009). During acclimation periods, birds had access to corn and water ad libitum. I released instrumented females with captured conspecific males or females to minimize possible dissolution of paired birds (Cox and Afton 1998). All capture, handling, and marking methods were approved by the Mississippi State University Institutional Animal Care and Use Committee protocol (# 10-070).

I tracked radio-marked females using trucks equipped with roof-mounted 4-element, null-peak antenna arrays, electronic compasses, Global Positioning System (GPS) units, and laptop computers with Location of a Signal software (LOAS 4.0; Ecological Software Solutions LLC, Hegymagas, Hungary; Cox et al. 2002, Gilsdorf et al. 2007). I calibrated electronic compasses to known locations of beacon transmitters ± 0.5° and trained technicians by triangulating beacon transmitters until they could successfully maintain an azimuth standard deviation of ≤ 3º (Davis et al. 2009). I tracked radio-marked mallards diurnally (30 min before sunrise to 30 min after sunset) throughout the study area, defined as an area of 80 km radius from capture locations (Cox and Afton 1997, Davis et al. 2009). I chose a random radio-marked bird to begin tracking and a random direction so that individual locations were gathered at random

intervals. When few females were available for tracking, I randomly chose a time of the day (i.e., morning, mid-day, afternoon) and corresponding nocturnal period to track females. Using a fixed wing aircraft equipped with left and right directional antennas, I pursued radio-marked mallards not detected from trucks after 2 consecutive days. The pilot flew at an altitude of 2,100-2,800 m and descended to 300 m elevation to pinpoint an individual (Gilmer et al. 1981). Upon locating a bird from the air, I recorded GPS coordinates along with distance and direction to a recognizable landmark and relayed information to technicians in telemetry trucks, so they could locate and triangulate birds' locations. I did not use aerially derived locations in data analyses, because accurate locations of birds were obtained from the ground on the same day following aerial location.

I attempted to record 3 azimuths to calculate each female location, but I continued to add azimuths until error ellipses fell within one habitat type or available vantage points were exhausted. Locations containing ≥ 3 azimuths comprised 96.5% of total locations, although, in some instances, road inaccessibility forced me to use bi-angulations (3.5% of locations) from the best available vantage points. If multiple triangulations occurred for an individual in a day, I used the first location, unless the subsequent location contained more azimuths. The LOAS software estimated point locations for each bird with a maximum likelihood estimator (Lenth 1981) using a bearing standard deviation of 3° (Davis et al. 2009). My technicians and I examined azimuths and point locations in real-time and immediately discarded apparently erroneous locations and re-triangulated the individual.

Statistical Design and Analyses

I replicated the experimental allocation of hunting regimes at Muscadine and Howard Miller WMAs established by St. James et al. (2013). Each WMA was divided relatively equally in area and randomly assigned to be hunted 2- or 4-days/week (St. James et al. 2013; Figure 3.2). On Tuesdays and Saturdays during the hunting season, each entire WMA was hunted on the 2- and 4-day/week areas (ALL); whereas, on Thursdays and Sundays, only the 4-day/week portion was open to hunting (HALF). Mahannah WMA had an established 4 day/week hunting regime, so the entire WMA was hunted on Mondays, Wednesdays, Fridays, and Saturdays. Public access was restricted at each WMA on non-hunting days (NONE) to provide a spatial and temporal waterfowl sanctuary (Fox and Madsen 1997). Lastly, WMAs were open for general public recreation (e.g., small game hunting, birding, etc.) during pre- and post-hunting seasons (CLOSED); this activity may have influenced use by radio-marked mallards. Therefore, I divided time periods (REGIME) into four categories for spatial and temporal statistical analyses (ALL, HALF, NONE, CLOSED).

Space Use by Radio-marked Mallards

I transferred female locations into a geographic information system (GIS) in ARCMAP 9.3.1 (Environmental Systems Research Institute 2005). I categorized daily locations of radio-marked mallards into one of five spatial categories: 1) TWO, locations on the WMA that occurred in the portion hunted 2 days/week; 2) FOUR, locations in areas hunted 4 days/week;, 3) SANC, locations on the WMA that occurred in sanctuary areas closed to public entry; 4) NWR, locations that occurred on Yazoo NWR where no waterfowl hunting is permitted; and 5) PRIV, locations that occurred on lands other than

WMA or NWR. Yazoo NWR was only considered as a spatial category for female mallards radio-marked at Muscadine WMA, because females marked at other locations did not use this or others NWR.

I used compositional analysis to examine spatial use of the landscapes relative to several explanatory variables (Aebischer et al. 1993). Unlike other space use analyses, where individual radio locations are the sampling unit, compositional analysis designates the individual as the sampling unit, thus reducing problems related to sampling intensity, unit sum constraint, and differential use by groups of animals (Kenward 1992, Aebischer et al. 1993). When necessary, I replaced zero values from unused categories with 0.002, a positive value one magnitude less than the smallest recorded non-zero proportion (Aebischer et al. 1993). I then computed a log ratio for all categories using proportional use of FOUR as the denominator, thus removing the unit sum constraint (Aitchison 1986). I chose proportional use of FOUR as the denominator because it represents the liberally hunted portion on the WMAs and allows direct comparison between it and conservatively hunted (TWO) and non-hunted SANC portions of the WMA. Results of the analysis are independent of the habitat category as the log ratio denominator but allow direct comparison to the habitat chosen as the denominator (Aebischer et al. 1993). I used the log ratios as response variables in a split-plot multivariate analysis of variance (MANOVA; SAS INST INC. 2011) to test for influences of the individual female, WINTER (2010-11 or 2011-12), and REGIME (ALL, HALF, NONE, CLOSED). I used split plots to calculate variation associated with individual females as the error term when testing for influences of winter and residual error to test for individual female and regime.

I began by analyzing full models and subsequently used backward stepwise procedures to eliminate non-significant ($P > 0.05$) explanatory variables (Wolfinger 1992).

When results from the MANOVA indicated disproportionate use, I tested proportional use of each habitat to use of FOUR, within levels of significant explanatory variables by testing whether least-square means of log-ratios differed from zero (Cox and Afton 1997, Davis et al. 2009). Estimates of proportional use of each habitat are presented as averages across individuals to facilitate biological interpretation within levels of significant ($P \leq 0.05$) explanatory variables from the final fitted model.

Temporal Use of Muscadine WMA by Radio-marked Mallards

I erected a remote data collection station in the geographic center of Muscadine WMA to record presence or absence of radio-marked female mallards every 20 minutes, 24 hours/day. The station consisted of a data-logging telemetry receiver (model 4500S, Advanced Telemetry Systems INC., Isanti, MN) linked to a 2 decibel omni-directional antenna mounted on a 15m mast. The telemetry receiver was powered by a 12-volt marine battery and was recharged through a 5-Watt solar panel. I programmed radio-marked mallard frequencies into the receiver and scanned for the presence of each frequency within detectable distance of the station approximately every 20 minutes (Ackerman et al. 2009). I placed a functioning reference transmitter at the outer boundary of the WMA and included it in all scans of transmitters to validate that the receiver was operating effectively during each scan. I also incorporated multiple false frequencies not associated with actual radio-transmitters into scans to record false detection rates (Ackerman et al. 2009). I interpreted lack of signal detection as true absence of the individual from the WMA when the system detected the reference

transmitter but not false frequencies (Ackerman et al. 2009). Occasionally, the remote station lost power and stopped recording, so I omitted data from such intervals from my analysis (Ackerman et al. 2009). I included data for individual females beginning 3 days post-release and excluded females from analysis that were deemed permanently missing from the study area (Chapters 1-2), or when a female died (Ackerman et al. 2009).

I was interested in diel presence or absence of radio-marked mallards at Muscadine WMA. To reduce volume and complexity of data accumulated by data-logging telemeter at the tower, I converted the presence/absence data originally acquired in 20-minute increments to an hourly scale. I considered a duck present (1) for the hour if it was recorded during ≥1 of the 3 incremental scans during that hour, or I considered a female to be absent (0) if she was not detected in any scan during the hour (Ackerman et al. 2009).

As part of temporal analysis of duck use of WMAs, I developed an index of hunter density. The MDWFP allocated hunters among wetland units available for hunting two-fold: 1) hunters were selected by a pre-season drawing and arrived the morning of the hunt for a guaranteed hunting unit, or 2) hunters were chosen via lottery the morning of the hunt to fill units available from pre-season draw holders that were absent the day of their hunt. The index was the proportion of available hunting units occupied by hunters given the allocated hunt regime (HUNTERS). For example, 7 hunting parties present at Muscadine WMA equates to 64% of the 11 available units occupied when half of the area is hunted (4-day/week only) or 33% if all 21 units of Muscadine are hunted that day (i.e., 2- and 4-day/week).

Radio-marked Mallard Attendance on Muscadine WMA

My goal in this primary analysis was to determine daily patterns of attendance by radio-marked mallards on Muscadine WMA during winter. I calculated the proportion of each day each living radio-marked mallard was present on Muscadine WMA by dividing the number of hours present in the day by 24 (Ackerman et al. 2009). I included only full 24 hour periods when the remote station was functional and I had no reason to exclude data (i.e., fixed transmitters recorded and no detection of false frequencies). I tested whether the proportion of the day spent on the WMA was related to DATE, REGIME, HUNTERS, and WINTER using linear regression (PROC MIXED; SAS Institute Inc. 2012). For statistical analysis, I arcsine-square root transformed proportion data and included the radio-marked female as a random effect to control for potential autocorrelation from repeated measures of individuals (Ackerman et al. 2009). I analyzed a set of 39 *a priori* models including combinations and 2-way interactions of aforementioned variables. I examined output statistics including Akaike's Information Criterion adjusted for small sample sizes (AIC_c), differences between AIC_c values of each model to the model with minimum AIC_c (ΔAIC_c), and model weights (w_i; Burnham and Anderson 2002). I considered a model to be competitive if parameters in the top model were not a subset (i.e., nested) of parameters in the competing model (Pieron et al. 2013).

Temporal Presence on Muscadine WMA

I investigated presence of radio-marked females by testing whether the probability of presence on Muscadine WMA was influenced by hour of the day (HOUR; circular continuous variable), REGIME, WINTER, and DATE using logistic regression (Proc GLIMMIX; SAS Institute Inc., Cary, N.C. 2012). To evaluate HOUR in the regression, I

converted hour (0-24 hrs) into a circular continuous variable by: 1) dividing the hour by 24 to scale it proportionately between 0 and 1, 2) multiplied this value by 2π to convert quotient to radians, and 3) calculated the sine (sin-hour) and cosine (cos-hour) of this value (Zar 1999, Ackerman et al. 2009). Steps 1-3 were necessary to properly evaluate hour (a circular variable) in the linear regression (Zar 1984). To evaluate models containing HOUR, I included both the sin-hour and cos-hour variables because they are required to accurately describe the HOUR relationship (Ackerman et al. 2009). I included each individual female as a random effect to control for the potential autocorrelation among repeated measurements of females (Ackerman et al. 2009).

Pseudo-estimation techniques render comparison inappropriate between models because true log likelihood is not estimated (Crozier et al. 2006, Pieron et al. 2013). Therefore, I used Laplace's methods to estimate marginal likelihoods, which are suitable for comparing among competing models within PROC GLIMMIX (SAS Version 9.3). I used Akaike's Information Criterion adjusted for small samples sizes (AIC_c) to calculate differences between models (ΔAIC_c) and used AIC_c weights (w_i) as a measure of support for models (Burnham and Anderson 2002). I considered a model to be competitive if parameters in the top model were not a subset (i.e., nested) of parameters in competing models (Pieron et al. 2013).

Results

Space Use by Radio-marked Mallards

Howard Miller WMA

I included 339 locations from 15 females captured in winter 2010-2011 in analysis of space use at Howard Miller WMA. I was unable to capture birds at Howard

Miller WMA in 2011-2012 because of late mallard arrival and unavailability of sanctuary to capture ducks. Individual radio-marked female was the only variable that influenced space use in the final fitted MANOVA (Wilks' Lambda = 0.11, $F_{42,96} = 2.54$, $P < 0.001$). I was unable to detect a difference in spatial use by REGIME (Wilks' Lambda = 0.59, $F_{9,71} = 1.91$, $P = 0.06$). Use of PRIV (0.70 ± 0.05 [SE]) by mallards was greater ($P < 0.001$) than SANC (0.07 ± 0.03), TWO (0.12 ± 0.03), and FOUR (0.11 ± 0.03; Figure 3.3). I was unable to detect a difference ($0.20 \leq P \leq 0.57$) in use between SANC and TWO, SANC and FOUR, or TWO and FOUR.

Mahannah WMA

Analysis of space use by females radio-marked at Mahannah WMA included 2,478 locations from 58 female mallards captured during winters 2010-2011 and 2011-2012. Because Mahannah WMA was hunted 4 days/week, I excluded the 2 days/week strata from the analysis. The final fitted MANOVA indicated space use varied by female (Wilks' Lambda = 0.15, $F_{114,212} = 2.88$, $P < 0.001$) and REGIME (Wilks' Lambda = 0.82, $F_{4,212} = 5.69$, $P < 0.001$). I was neither able to detect a difference in space use between winters (Wilks' Lambda = 1.00, $F2,56 = 0.03$, $P = 0.97$) nor a difference ($P \geq 0.22$) in use of PRIV among paired combinations of ALL, NONE, and CLOSED.

The hunt area (FOUR) was used less than ($P \leq 0.02$) PRIV during all REGIME periods (Figure 3.4). The SANC portion of the WMA was used more ($P < 0.001$) than the hunt area during ALL, but there was no detectable differences (Ps ≥ 0.23) between use of SANC and FOUR during CLOSED or NONE. Mahannah SANC was used more ($P = 0.001$) during ALL than CLOSED, and there was no difference ($P \geq 0.06$) in SANC use between ALL and NONE or NONE and CLOSED.

Muscadine WMA

I included 1,778 locations from 35 females radio-marked at Muscadine WMA in analysis of space use for winters 2010-2011 and 2011-2012 there. The final fitted MANOVA included explanatory variables of female (Wilks' Lambda = 0.01, $F_{136,393}$= 6.78, $P < 0.001$) and REGIME (Wilks' Lambda = 0.63, $F_{12,260} = 4.08$, $P < 0.001$; Figure 3.5). I was unable to detect an effect of winter on space use (Wilks' Lambda = 0.93, $F_{4,31} = 0.57$, $P = 0.69$). Muscadine SANC was used less ($P < 0.05$) than FOUR during all REGIMEs, and SANC was used least ($P < 0.001$) relative to FOUR during CLOSED. There were no differences (Ps ≥ 0.52) in use of SANC relative to FOUR among ALL, HALF, or NONE. I was unable to detect differences (Ps ≥ 0.21) between use of TWO and FOUR among REGIMES, and use of TWO compared to FOUR was similar (Ps ≥ 0.08) among REGIMES. Among all regimes, PRIV was used more (Ps < 0.001) than FOUR. There were no differences (Ps ≥ 0.06) in use of PRIV relative to FOUR among regimes. Lastly, NWR was used more (Ps < 0.001) than FOUR during all REGIMEs. Use of NWR relative to FOUR was greater (Ps < 0.001) during NONE, HALF, and ALL than for CLOSED.

Temporal Use of Muscadine WMA by Radio-marked Mallards

Radio-marked Mallard Attendance on Muscadine WMA

The proportion of 24 hr days spent on Muscadine WMA by female mallards was best explained by the interaction of DATE and WINTER ($w_i = 0.33$; Table 3.1). This interaction was present in 4 of 5 top models accounting for 81% of model weights. Three models were within 2 ΔAIC_c of the most parsimonious model of which two included DATE*WINTER with additive effects of HUNTERS or REGIME. There was no

significant difference ($F_{1,31}$ = 0.22, P = 0.65) in intercepts between winters 2010-2011 (0.59) and 2011-2012 (0.66). However, the proportion of the day spent on Muscadine WMA declined as winter progressed, but the rates of decline differed between WINTERs ($F_{1,1085}$ = 200.7, P < 0.001); the decline was greater in winter 2011-12 (0.9%/day) than in winter 2010-2011 (0.51%/day).

Temporal Presence on Muscadine WMA

Several variables best explained presence of radio-marked female mallards on Muscadine WMA including DATE, sin-hour * REGIME and cos-hour * REGIME (w_i = 0.65; Table 3.2). Remaining explanatory weight was in a model that included all variables in the top model plus WINTER (w_i = 0.35, ΔAIC_c = 1.2). All other models had $\Delta AIC_c \geq 26.23$ (w_i = 0). Probability of presence of females was negatively correlated with DATE through winter and, on average, females were 46% and 16% more ($P \leq$ 0.004) likely to be present on the WMA during CLOSED than during ALL or NONE, respectively.

Moreover, females were 32% and 26% more (P < 0.001) likely to be present on Muscadine WMA during HALF and NONE than during ALL, respectively. There was moderate evidence (P = 0.054) for an 11% difference in the probability of being present on the WMA during CLOSED and HALF but no detectable difference (P = 0.44) between HALF and NONE. The probability of presence was greatest at 03:00 hours but steadily declined until birds were least likely to occur at15:00 hours. I did not detect a difference ($P \geq 0.14$) in the HOUR*REGIME interaction term between CLOSED and HALF, CLOSED and NONE, or HALF and NONE. However, there was a significant

difference ($P < 0.001$) in the HOUR*REGIME interaction between ALL and CLOSED, ALL and HALF, or ALL and NONE.

Discussion

Space Use

I found that weekly hunting frequency on WMAs influenced use of WMAs and adjacent lands for female mallards captured and marked at Mahannah and Muscadine WMAs but not at Howard Miller WMA. Females originally radio-marked on Howard Miller WMA used areas hunted 2- or 4-days/week and sanctuary equally during winter, but private lands were used most. St. James et al. (2013) found no difference in mallard abundance in wetland units hunted two or four days/week at Howard Miller and Muscadine WMAs, nor did they find a difference in mallard use of sanctuaries when all, half, or none of each WMA was hunted. In addition to creating spatial sanctuary, MDWFP WMAs provide temporal sanctuary by ending hunting at noon on hunt days to encourage waterfowl use of WMAs between hunts (Bregnballe and Madsen 2004, St. James et al. 2013). Therefore, radio-marked mallards in my study may have exploited Howard Miller WMA in the afternoon when hunters were absent. Although I did not empirically test time of day in my spatial analysis, 87% of radio-marked female locations on Howard Miller WMA during the hunting season occurred in afternoons. Dooley et al. (2010) found mallards subjected to anthropogenic disturbance (walking or shooting) during morning returned to the site of disturbance 23-38% of those afternoons. Alternatively, radio-marked mallards in my study may have occupied a non-hunted unit(s) during a morning hunt at Howard Miller WMA. Hunting participation at the WMAs where I marked mallards typically wanes as hunting season progresses, so it is

not uncommon for some hunting units to be unoccupied by hunters on hunt days (H. Havens, MDWFP, unpublished data).

I was only able to capture 15 female mallards at Howard Miller in winter 2010-2011, and capture occurred late in the waterfowl hunting season ($\bar{x}$ capture date = 16 January 2011). Therefore, I obtained 76% of all locations of marked birds after the hunting season so it is likely that I could not adequately address bird use of WMAs in other periods. In all likelihood, this prohibited me from detecting any differences in mallard use among REGIMES, if they existed. Moreover, patterns of WMA use by mallards at Howard Miller, which typified great use of private lands and little use of the WMA itself, are consistent with mallard use of Muscadine and Mahannah WMAs when hunting season was closed.

Similar to mallards captured at Howard Miller WMA, radio-marked females at Mahannah used private lands extensively although patterns of use varied among REGIME (Figure 3.4). Mahannah's sanctuary received its greatest use and was used more than hunted units on days the WMA was hunted. These patterns suggest that inviolate sanctuary was indeed important to mallards at Mahannah WMA during the hunting season as reported in other studies (Madsen and Fox 1995, Fox and Madsen 1997, Madsen 1998). Similarly use of spatial sanctuary habitats by northern pintails in southwestern Louisiana was greater during hunting season than prior to or after hunting seasons (Cox and Afton 1997).

Radio-marked female mallards in my study were equally likely to use hunted units and sanctuary during the hunting season when the WMA was closed. This behavior suggests mallards may be adept at exploiting habitats and resources when they are not

being hunted and use them similarly to inviolate sanctuary during the hunting season. Dooley et al. (2010) found that 70-75% of mallards exposed to anthropogenic disturbance returned to the site of disturbance in ≤ 1 day. Therefore, a single day respite may be adequate for waterfowl to realize and exploit resources in hunted units, provided they have a suitable inviolate sanctuary on hunted days. Hunted units and sanctuary were used equally when waterfowl hunting season was closed; however, the sanctuary was used least during this period. This decline in use of sanctuary is analogous to patterns of refuge use by pintails witnessed by Cox and Afton (1997), and refutes Tamisier's (1976) hypothesis that diurnal use of refuges occurs independently of hunting. Davis et al. (2009) witnessed a similar decline in refuge use by radio-marked mallards following the closure of hunting season in 1of 2 winters in Louisiana and Arkansas. Private lands adjacent to Mahannah WMA were used more by mallards than hunted units of the WMA throughout winter. However, radio-marked mallards were not inclined to use private lands greater during any particular REGIME indicating that waterfowl may react similarly to hunting on adjacent private lands and that of Mahannah. Moreover, because Mahannah's sanctuary was used greater than hunted units when the WMA was hunted, and sanctuary use did not decline when the WMA was not hunted during hunting season, I hypothesize that Mahannah's refuge must either be large enough and-or physically positioned, where it accommodates birds using the WMA but also those disturbed on adjacent private lands.

Landscape use by radio-marked mallards captured at Muscadine WMA varied by REGIME, and private lands and Yazoo NWR were used extensively throughout winter (Figure 3.5). Private lands vary in their hunting intensity, and waterfowl respond to

different levels of disturbance at a scale beyond that of the WMA (St James 2011, St. James et al. 2013). Radio-marked mallards also apparently modify their use of private lands according to levels of disturbance effects. I predicted use of private lands versus WMA units hunted 4-days per week would have been less when hunting season was closed, predicting that birds would increase use of the WMA when waterfowl hunting season was closed. However, use of private lands remained great following hunting season closure. A possible explanation is that waterfowl modify their temporal use of WMAs through winter where they exploit hunted habitats nocturnally to avoid risk of hunting related mortality (Cox and Afton 1997, Casazza et al. 2012). Cox and Afton (1997) found that pintails used moist-soil and flooded rice fields primarily at night, presumably to escape diurnal hunting pressure. If mallards in my study and ducks in general behave similarly in their use of WMAs, perhaps forage may be exhausted on WMAs before or by the end of waterfowl hunting seasons (Hagy and Kaminski 2012), causing waterfowl to disperse and use private lands.

Yazoo NWR was also an important resource for mallards radio-marked at Muscadine WMA. Yazoo NWR was used more than Muscadine WMA units hunted 4-days per week during winter. Yazoo was most used by radio-marked mallards during open waterfowl hunting season and less frequently used when hunting season was closed. Use of Yazoo NWR by marked mallards was lowest when waterfowl hunting season was closed, which was similar to patterns of mallards and northern pintails in other studies (Davis et al. 2009, Cox and Afton 1997). When sanctuaries of NWRs are available, waterfowl use them to avoid harvest or other disturbance during hunting season (Roy et al. 2013). Females used private lands greatest when hunting season was closed,

presumably to exploit food resources that become depleted on the NWR (Hamilton and Watt 1970) and seek isolation with male mate because many females are paired by late January (Heitmeyer 2006).

Relative to other portions of Muscadine WMA, radio-marked mallards used WMA units hunted two or four days/week equally. St. James et al. (2013) also reported no difference between abundances of mallard, northern shoveler, green-winged teal, and all ducks combined between 2- and 4-day/week hunt regimes, and harvest of these species and total ducks did not differ between these hunting regimes (St. James 2011). These results suggest that more restrictive hunting regimes (i.e., 2-days/week) may not necessarily result in greater use by individual mallards. Fox and Madsen (1997) claimed that intermittent hunting was not an effective strategy to minimize hunting disturbance on waterfowl and that timing between hunting events should be weeks and not days. Because the primary goal of WMAs is to provide public hunting opportunity, restricting hunting to ≤ 1-day/week would not be endorsed by public land hunters in Mississippi. Therefore, given similar levels of use of wetlands by radio-marked female mallards with 2- or 4-days/week, coupled with previous results on these study areas (St. James 2011, St. James et al. 2013), I suggest WMAs can be hunted 4-days/week without negatively influencing use and harvest of ducks.

Radio-marked females exhibited negligible (≤ 3.3%) use of sanctuary at Muscadine WMA and were more likely to use the area hunted 4-days/week throughout winter. Use of sanctuary was consistent among hunted and closed periods within hunting seasons. My results were consistent with St. James et al. (2013) who found no difference in abundances of mallard, northern shoveler, green-winged teal, or all ducks combined

among hunted and non-hunted periods of hunting seasons at Muscadine. Analogous to use of NWRs, use of Muscadine WMA sanctuary by radio-marked mallards was least during the closed hunting period. This suggests that sanctuaries may have been used periodically as an escape from hunting pressure on Muscadine or other hunted lands during the waterfowl season. However, most females radio-marked at Muscadine WMA used Yazoo NWR as spatial sanctuary during hunting season. The sanctuary at Muscadine WMA is 80 ha and merely separated from areas hunted 2- and 4-days per week by a ditch and a road, respectively (Figure 3.6). In contrast, Yazoo provides approximately 2,500 ha of various wetland types and lands that are closed to waterfowl hunting, with the exception of two youth weekend waterfowl that take place near the end of the regular waterfowl hunting season each winter. Therefore, close (< 30 m) proximity of hunting units and sanctuary at Muscadine may have influenced mallards to bypass that sanctuary and fly to Yazoo to avoid hunt disturbance.

Fox and Madsen (1997) discussed sanctuary design in relation to escape flight distances (EFD); i.e., distance between a bird and source of disturbance which causes a bird to take flight. They concluded that sanctuary size should be equivalent to an area with a diameter 3 times EFD of the most sensitive species (Fox and Madsen 1997). Dooley (2008) measured EFDs for radio-marked mallards along the Platte River corridor in northeastern Colorado and found EFDs ranged from 5 to 203 meters but averaged 65 meters. Therefore, commensurate with Fox and Madsen's (1997) suggestion and using a conservative estimate for mallard EFD (203 m), I deem an appropriate sanctuary hypothetically as >600 m wide.

Based on my observations, Mahannah WMA seems to have adequate space to accommodate hunters, provide quality hunting experiences, and provide sanctuaries that ducks use during hunt days. In contrast, I question whether space to accommodate these three dynamics is adequate at Muscadine and Howard Miller WMAs. At Muscadine and Howard Miller WMAs, the centers of each sanctuary are only 375-450 m from hunted units. At Mahannah, the sanctuary center is > 900 m from a hunted area and a levee with a 25 m buffer strip of trees on each side separates the sanctuary and hunted area (Figure 3.7). Physical barriers separating sanctuaries from hunted areas do not exist at Howard Miller (Figure 3.8). Furthermore, merely a 10 m wide ditch and tree line divides one east portion of the sanctuary from a hunted area at Muscadine WMA (Figure 3.6). Lack of sanctuary use at Howard Miller and Muscadine WMAs may have resulted from sanctuaries existing too close to hunt areas, an inadequately wide physical barrier between the sanctuary and hunted areas, or some combination of these. Dooley et al. (2010) reported that radio-marked mallards flew 3-5 km following shooting disturbance. If mallards in my study require similar distances between hunted lands and refugia, I suggest that MDWFP re-evaluate sanctuary size and placement at Muscadine and Howard Miller WMAs. My and future research should help refine our understanding of mallard use of WMAs in Mississippi and will be relevant for conservation planning and future WMA design. Given the apparent size, juxtaposition, or otherwise effective utility of the refuge at Mahannah, it may serve as an important model for refuges at other existing WMAs, or as a possible design for sites that will be developed as WMAs in the future in Mississippi and elsewhere.

A small proportion (3-20%) of radio-marked females continued to use hunted portions of WMAs on days in which they were hunted. However, these birds could have used hunted portions of the WMA primarily after the noon hunting closure. I did not specifically test morning versus afternoon use of WMAs by radio-marked females on hunted and non-hunted days; therefore, I can only speculate on this relationship. Dooley et al. (2010) found that 23% of radio-marked mallards exposed to shooting returned to the site of disturbance the following afternoon. Therefore, noon hunting closure may be sufficient to allow mallards to exploit the WMA in the afternoon.

Cox and Afton (1997) found that northern pintails responded to hunting pressure in moist-soil and rice habitats by using these habitats nocturnally during hunting season. I did not test nocturnal space use in relation to REGIME on WMAs because my data were limited, however, evidence from a remote data collection station may enhance our understanding of nocturnal use of Muscadine WMA in relation to hunting season.

Temporal Use

The remote station documented use of Muscadine WMA by radio-marked females that otherwise would have been immeasurable. I detected a decline in the probability radio-marked females were present as well as the proportion of daily use by these females on Muscadine WMA through winter. Moreover, the proportion of the day spent on Muscadine declined faster in winter 2011-2012 than winter 2010-2011. This outcome could have been explained by effects of accumulated disturbance through hunting season (Madsen and Fox 1995). Dooley et al. (2010) reported 70-75% of radio-marked mallards returned to the location of a disturbance ≤ 1 day following perturbations. However, Dooley et al. (2010) only subjected mallards to a single disturbance per month and it is

unknown how cumulative or repetitive disturbance may influence individual trends in departure or return rates (Fox and Madsen 1997). There is some evidence that waterbirds habituate to predictable and directional stimuli, but hunting disturbance is neither (Burger 1981, Fox and Madsen 1997).

Alternatively, declining use of the WMA in winter could have resulted from decreased levels of food remaining where foraging profitability decreased given the presence of hunters or natural predators of ducks (i.e., giving-up density; Brown and Kotler 2004). Basically, the risk of injury or mortality to an individual mallard outweighed the benefits of foraging in a patch of decreased food density, rendering birds' movement to other patches providing an increased benefit-risk ratio (Brown and Kotler 2004). Numerous studies have reported changes in space use in response to spatiotemporal differences in predation risk over a given area for mammals, but no such study exits for waterfowl (Brown 1988, Van Der Merwe and Brown 2008, Tolon et al. 2009).

In addition to direct harvest, predators and human hunters also induce nonlethal impacts on waterfowl causing them to increase alertness which could cause them to lose valuable foraging time (Madsen and Fox 1995). Frederick et al. (1987) reported that harvest was less important than its associated disturbance to feeding geese by hunters in reducing population size in simulations of lesser snow geese (*Chen c. caerulescens*). To maintain body condition, birds that lose foraging time must compensate somehow, either through increased foraging time or exploiting resources at times of the day when predator activity decreases or ceases (McNeil et al. 1992, Madsen and Fox 1995).

Waterfowl may nocturnally exploit food or other resources that human activities may render less or not available diurnally (Madsen and Fox 1995). Furthermore, Dooley et al. (2010) reported that radio-marked mallards exposed to shooting disturbance were unlikely to return to that site diurnally but were equally likely to return nocturnally with mallards not disturbed diurnally. Similarly, I found greater presence of radio-marked females on Muscadine WMA during nights than days. I did not observe nocturnal activities but speculate that feeding was a primary activity. Anderson and Smith (1999) stated that all waterbirds observed in seasonal emergent playa wetlands were feeding at night, whereas during the daytime, feeding and other activities occurred. McNeil et al. (1992) discussed two primary motives related to nocturnal foraging theory: 1) foraging may be more profitable and safer than diurnally and 2) birds may resort to nocturnal feeding because they do not meet forage requirements diurnally. Both hypotheses are likely interrelated, but for mallards on publicly hunted WMAs, I surmise mallards forage nocturnally to avoid harvest or anthropogenic disturbance during diurnal periods.

Although patterns of increased nocturnal use of Muscadine WMA is likely related to legal diurnal hunting activity, habitat management on the WMA may also explain nocturnal behavior. Anderson and Smith (1999) observed greatest densities of waterfowl using playas containing moist-soil vegetation at night in the southern high plains of Texas. Although hunting disturbance could not be ruled out as a factor exacerbating nocturnal use by ducks, hunting pressure was low in the region (Anderson and Smith 1999). Similarly, in my study, use of Muscadine WMA was greatest at night when hunting was absent. Previous research suggested that waterfowl may select moist-soil wetlands nocturnally for other reasons, such as natural predator avoidance, increased

invertebrate availability, or thermal cover (Evans 1987, Anderson and Smith 1999, Esser et al. 2008). Waterfowl may be innately or behaviorally induced to move nocturnally and it is likely that several interacting variables influence this behavior (Jorde and Owen 1988). This pattern predominates across wide taxa of waterfowl in many areas of North America (Bossenmaier and Marshall 1958, Nilsson 1970, Jorde and Owen 1988, Miller et al. 1989, Cox and Afton 1997, van Groenigen et al. 2003).

Radio-marked females spent similar proportions of the entire day on Muscadine WMA regardless of whether the WMA was hunted or it was closed to hunting that day. This pattern may have resulted because most mallard use of the WMA was nocturnal; therefore, morning hunting may have been an insignificant influence on daily time birds spent on the WMA. However, radio-marked birds were most likely to be present on the WMA when hunting was closed and least likely when the entire WMA was hunted. This pattern suggests there may have been a cumulative effect caused by hunting, whereby birds tended to abandon the WMA sooner that when only half the WMA was hunted. Because there were no detectable differences in hourly patterns of radio-marked mallards when season was closed, the WMA was not hunted, or only half the WMA was hunted, hunting only half the WMA may not cause increased abandonment of mallards and perhaps other ducks from the WMA. I did not analyze nocturnal spatial use of Muscadine WMA, but mallards may have used those wetlands hunted only 2-days per week nocturnally more so than when wetlands hunted four-days per week. Therefore, those birds may not have been disturbed when only half the WMA was hunted because hunters were present on the opposite half of the WMA.

The ideal free distribution model posits that animal populations distribute themselves according to available resources and density of coexisting animals in an attempt to maximize individual fitness (Fretwell 1972). Although I did not measure food abundance in my study, food abundance and associated potential duck-energy days (DEDs) may have differed between units hunted 2- or 4-days/week. St. James (2011) quantified DEDs at Howard Miller and Muscadine WMAs during her study and found potential DEDs were greater in areas hunted 2-days/week than those hunted 4-days/week but densities of waterfowl were similar. Nonetheless, potential differences in DEDs during my study also may have influenced mallard use of Muscadine WMA. Future experiments should concurrently measure food resources, disturbance, and waterfowl response to determine interrelated influences on habitat use by waterfowl.

Future priorities for research involving mallard use of hunted areas should include acquiring additional data on nocturnal use of hunted and sanctuary areas, as well as diel use of areas (e.g., sunrise-noon, noon-sunset, sunset-sunrise). Quantification of habitat-related diurnal and nocturnal activity budgets for waterfowl in the MAV should also be a future research priority, so an understanding of behavioral use of habitats can help guide development and management of suitable habitats for mallards and other waterfowl on public and private lands. Moreover, researchers should design and implement disturbance experiments to further reconcile competing hypotheses related to nocturnal foraging theory in waterfowl (Jorde and Owen 1988, McNeil et al. 1992). Similar to studies in agricultural environments (Greer et al. 2008), scientists should study foraging giving-up densities of waterfowl concurrently in habitats hunted and not hunted (i.e., sanctuary) in the MAV. One testable hypothesis would be that dabbling ducks abandon

food patches at higher seed densities when there is a risk of mortality and exploit less rich patches in sanctuaries wherein risk of death is little or none.

Management Implications

Among my research priorities was to understand if radio-marked mallards differentially used WMAs relative to two hunting regimes. Data relating to this objective are relevant for resource management on private and public lands in the Mississippi Delta. Moreover, use of hunted and sanctuary sites by mallards is extremely relevant to MDWFP in (1) assessing current hunting strategies, such as number of days hunted per week or proportions of WMAs hunted, (2) re-evaluation of current sanctuary size, juxtaposition, or overall function, and (3) consideration of these sanctuary parameters for future land acquisition and wetland restoration.

Prior to St. James et al's. (2013) and my studies, Mahannah WMA was hunted 4 days/week, whereas Howard Miller and Muscadine WMAs were hunted 3- and 2-days/week, respectively. Given waterfowl abundance and harvest observed in these differentially hunted units (St. James 2011, St. James et al. 2013) and the behaviors I documented in my radio-marked mallards, our data support hunting on Howard Miller and Muscadine WMAs 4 days/week without negative consequences to mallard use and other dabbling duck use of the WMAs.

My analyses were not designed to evaluate current temporal regulations regarding hunting closure at noon. However, hourly use patterns of Muscadine WMA indicate that radio-marked mallards began to return after 15:00 hr., therefore, afternoon waterfowl hunting could interfere with mallards meeting important biological and social requirements. Moreover, Bregnballe and Madsen (2004) found that waterfowl hunting

near sunset resulted in significantly lower numbers of mallards present the following day. Therefore, given results from my study and that of previous research, I suggest hunting be terminated at noon but that wetland units be hunted 4-days per week at Muscadine and Howard Miller WMAs. Nonetheless, the hypothesis that mallards will be discouraged from using wetland units a day(s) following late afternoon hunting may be a topic for future research.

Despite these patterns for mallards, numerous other species of waterfowl use WMAs and may have differential responses to increased hunting intensity. Mallards, northern shoveler, and green-winged teal were the most abundant and harvested species at Howard Miller and Muscadine WMAs (St. James 2011, St. James et al. 2013). Ackerman et al. (2006) found that waterfowl with shorter life-spans (i.e., green-winged teal) were more risk-inclined than those with a prolonged life-span (i.e., mallard). Therefore, green-winged teal and northern shovelers may respond differently than mallards to increased hunting disturbance on WMAs. Specifically, increased hunting pressure may result in increased harvest susceptibility of green-winged teal because they will take more risks to access food resources (Ackerman et al. 2006).

Based on patterns of use of sanctuary habitat by radio-marked mallards at Mahannah WMA, I advocate that its sanctuary be used as a template for design of sanctuaries at other publicly hunted areas in the MAV, assuming available area exists. The sanctuary size and its distance and physical barrier from hunted units may have encouraged use by mallards during hunting seasons. At Howard Miller WMA, the sanctuary is limited by its distance and lack of physical barrier separating it from hunted units. A 20-25 m strip of fast growing trees (e.g., cottonwood [*Populus* spp.] or willow

[*Salix nigra*]) may provide a suitable barrier between hunting units and sanctuary habitat. I advocate that sanctuary habitat is especially important at Howard Miller WMA because there are no NWRs or other habitats that function as waterfowl sanctuary in the immediate region. In contrast, sanctuary was used less than the hunted units throughout winter at Muscadine WMA. Because Yazoo NWR is approximately 10 km away and received extensive use by mallards marked at Muscadine WMA, managers may contemplate modifying the current sanctuary areas on Muscadine WMA relative to hunted units to increase public opportunity. Another novel consideration for MDWFP might be to transform the physical confines of the sanctuary at Muscadine. For example, the sanctuary at Muscadine is currently composed of 13 individual impoundments. I encourage MDWFP to entertain the notion of eliminating the interior levees of the sanctuary cells to create one large and single impoundment. Moreover, Fox and Madsen (1997) advocate against small refuge units because the buffer-core ratio greatly diminishes. Therefore, creating a continuous impoundment would maximize core area to minimize disturbance to waterfowl. Furthermore, buffers of trees could be established along the interior perimeter of one large sanctuary to further reduce disturbance to waterfowl. I do realize that trees might encourage roosting by raptors or jeopardize levee function, but trees could be established away from the levee so they did not interfere with structural integrity of the levee itself. Finally, the MDWFP may seek to purchase new WMAs in proximity to NWRs or private lands providing sanctuary areas. Thus, for current and future WMAs, sanctuaries and suitable complexes of habitats should be integrated to promote waterfowl use and survival during winter (Chapters 1 and 2). Provision of complexes of suitable habitats is fundamental to promoting waterfowl

hunting recreation and subsequent philopatry to WMAs by waterfowl within and among years.

Mallards were most likely to use Muscadine WMA at night regardless of within-winter periods (i.e., hunting or not hunting). This pattern may have been a result of cumulative effects of hunting, but it may also have related to moist-soil management on the WMA, where food was abundant and birds could access it at night (Anderson and Smith 1999). Forested habitats were the most diurnally used habitat by mallards in Louisiana and Mississippi during winter (Davis et al. 2009, Chapter 2). Because each hunting unit at Muscadine WMA consists of 2-4 individual impoundments, managers may contemplate afforestation of a single impoundment or parts of impoundments to increase diurnal use by mallards (Chapter 2). This approach might also encourage use by some other species, such as green-winged teal and possibly wood ducks, but it is unknown how other species such as blue-winged teal or northern shoveler might be affected. However, use of the WMA would not be discouraged because some units would remain unchanged. Lastly, I did not empirically assess temporal use of Howard Miller WMA by radio-marked mallards, but I suggest that afforestation in portions of the WMA could also increase diurnal use by mallards.

Table 3.1 Top 7 models explaining the proportion of a day spent on Muscadine Wildlife Management Area.

Model[a]	k^b	AIC_c[c]	ΔAIC_c[d]	w_i[e]
Date*Winter	4	1148.4	0.00	0.33
Date*Winter+Hunters	6	1149	0.60	0.24
Date*Winter+Regime	7	1150	1.60	0.15
Date+Regime*Winter	9	1150.3	1.90	0.13
Date*Winter+Regime+Hunters	9	1150.9	2.50	0.09
Regime*Winter+Date+Hunters	11	1152.4	4.00	0.04
Date*Regime	8	1155.8	7.40	0.01
…		…	…	…
Null	1	1326.4	178.00	0.00

[a] See methods for description of variables.

[b] Number of estimated parameters.

[c] Akaike's Information Criterion adjusted for small sample sizes.

[d] Difference between current model and the model with lowest AICc.

[e] Model weight.

For radio-marked female mallards in the south Mississippi Alluvial Valley of Mississippi during winters 2010-2011 and 2011-2012.

Table 3.2 Top 8 models explaining the probability of presence of radio-marked female mallards on Muscadine Wildlife Management Area.

Model[a]	k[b]	AIC_c[c]	ΔAIC_c[d]	w_i[e]
Hour+ Regime + Date + Hour*Regime	13	17692.5	0	0.65
Hour + Regime + Winter + Date + Hour*Regime	14	17693.7	1.2	0.35
Hour + Regime + Date	7	17718.8	26.2	0.00
Hour + Regime + Winter+ Date	8	17720.3	27.8	0.00
Hour + Date	4	17748.2	55.6	0.00
Hour + Winter + Date	5	17749.7	57.1	0.00
Regime + Date	5	18183.7	491.1	0.00
Regime + Winter + Date	6	18185.2	492.6	0.00
…	…	…	…	…
Null	1	20996.9	3304.4	0.00

[a] See methods for description of variables. Hour = combination of sin-hour and cos-hour.

[b] Number of estimated parameters.

[c] Akaike's Information Criterion adjusted for small sample sizes.

[d] Difference between current model and the model with lowest AICc.

[e] Model weight.

For radio-marked female mallards in the south Mississippi Alluvial Valley of Mississippi during winters 2010-2011 and 2011-2012.

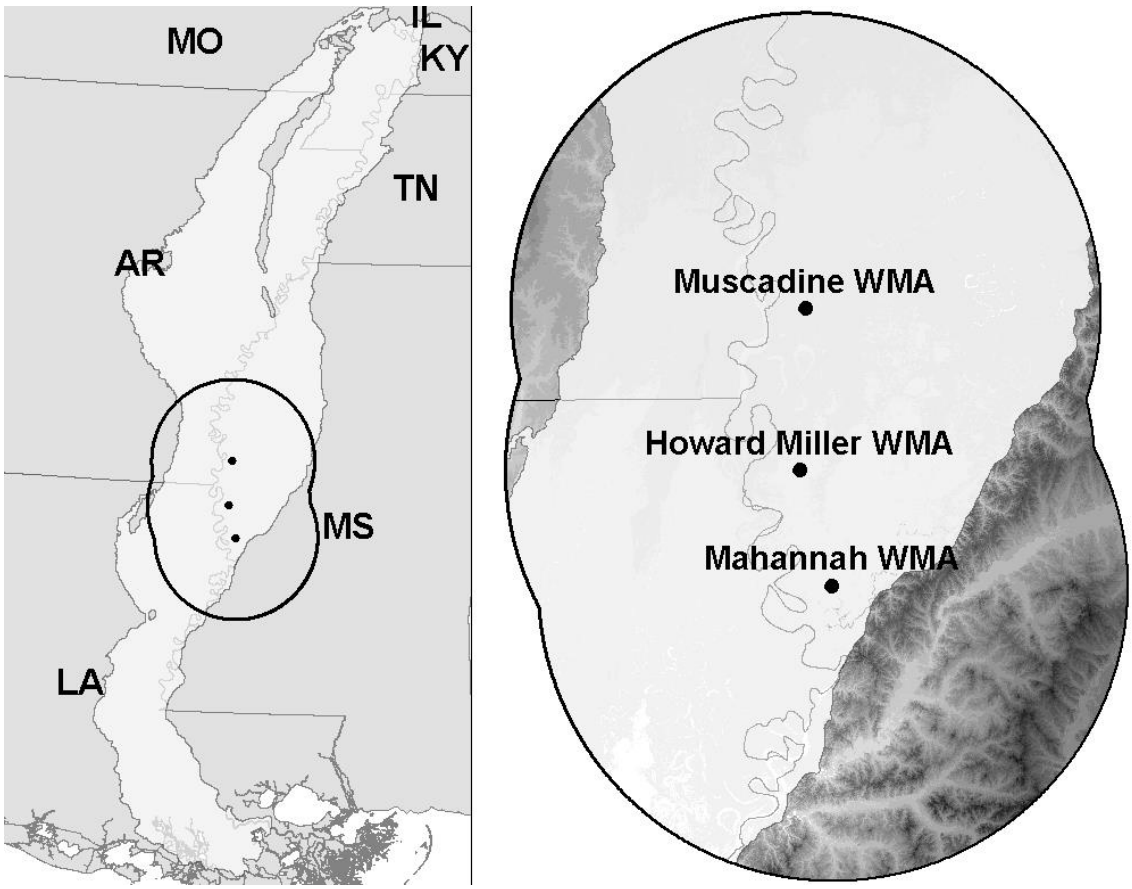

Figure 3.1 Locations where female mallards were captured, radio-marked and tracked.

Capture locations (black dots) on Wildlife Management Areas (WMA) in the Mississippi portion of the Mississippi Alluvial Valley and 80 km surrounding search area (black circle) during winters 2010-2012.

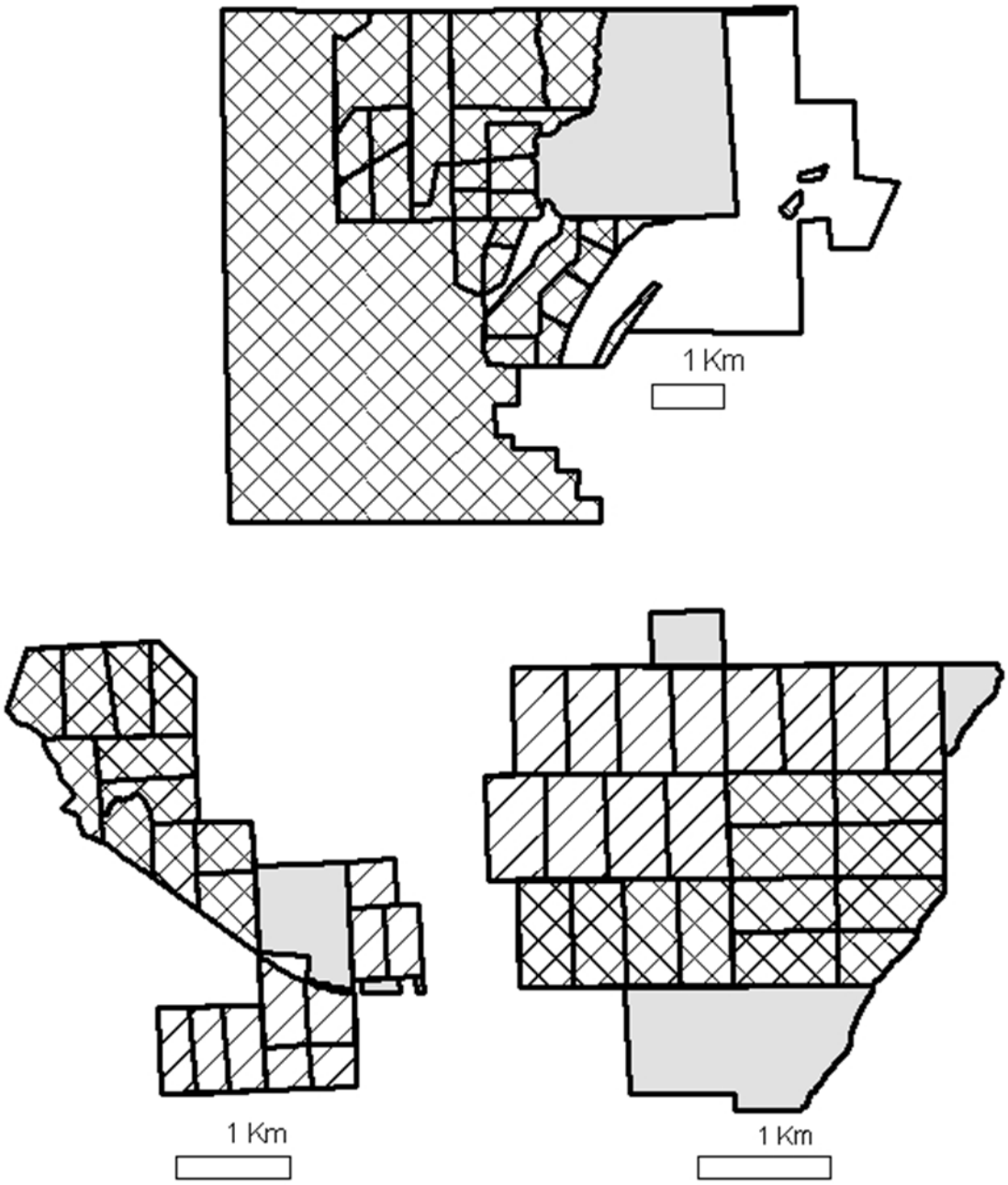

Figure 3.2 Juxtaposition of hunted (TWO. [hatch] or FOUR. [crosshatch]) and sanctuary (SANC [solid gray] wetland units at Mahannah (top), Muscadine (bottom left), and Howard Miller (bottom right) Wildlife Management Areas.

Within the south Mississippi Alluvial Valley of Mississippi during winters 2010-2011 and 2011-2012.

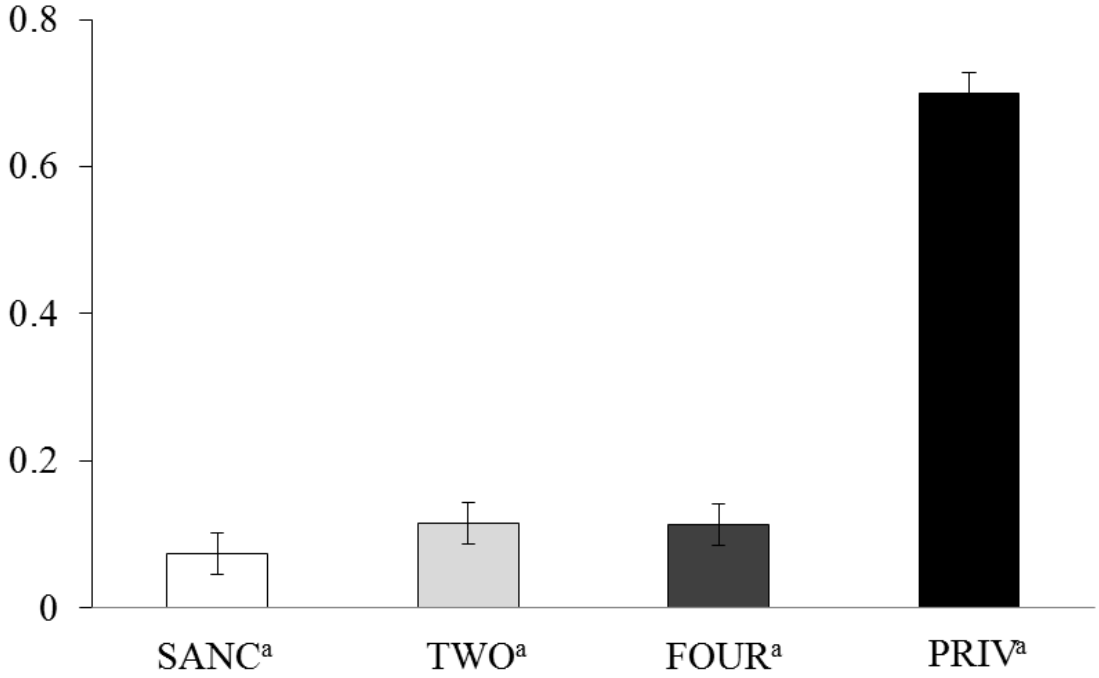

Figure 3.3 Mean use (± SE) of Howard Miller Wildlife Management Area units under variable hunt management regimes and private lands.

[a] SANC = non-hunted sanctuary wetlands of the Wildlife Management Area. TWO = wetlands on the WMA hunted 2 days/week. FOUR = wetlands on the WMA hunted 4 days/week. PRIV = private lands.

For female mallards radio-marked at Howard Miller WMA in the south Mississippi Alluvial Valley of Mississippi during winter 2010-2011.

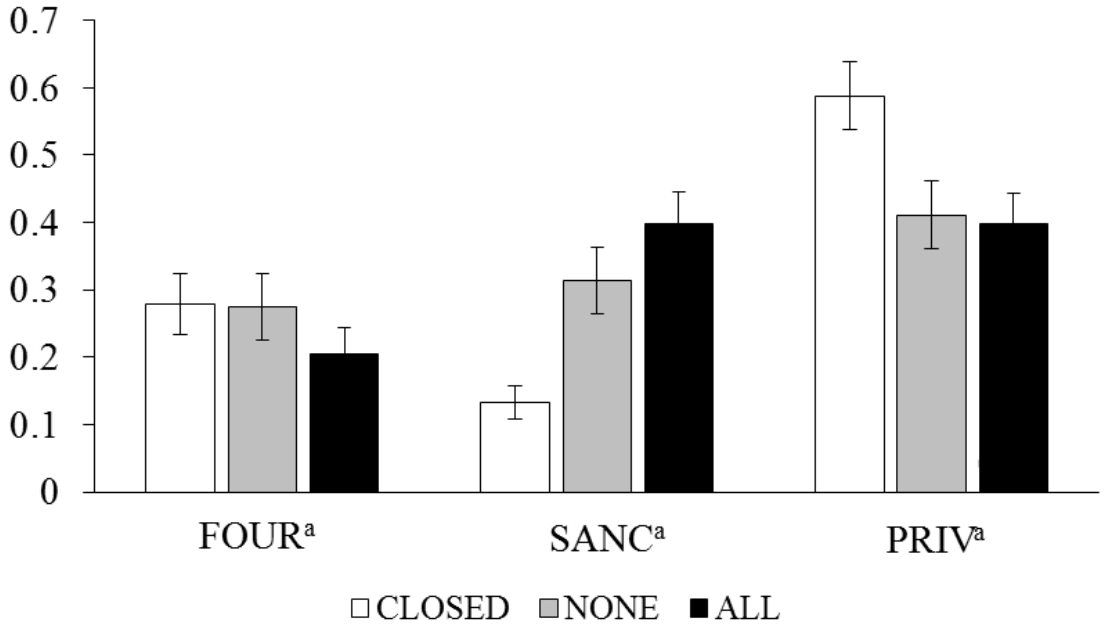

Figure 3.4 Mean use (± SE) of Mahannah Wildlife Management Area units under variable hunt management regimes and private lands

[a] SANC = non-hunted sanctuary portion of the Wildlife Management Area. FOUR = hunted portion of the WMA. PRIV = private lands.

For female mallards radio-marked at Mahannah WMA in the south Mississippi Alluvial Valley of Mississippi during winters 2010-2011 and 2011-2012.

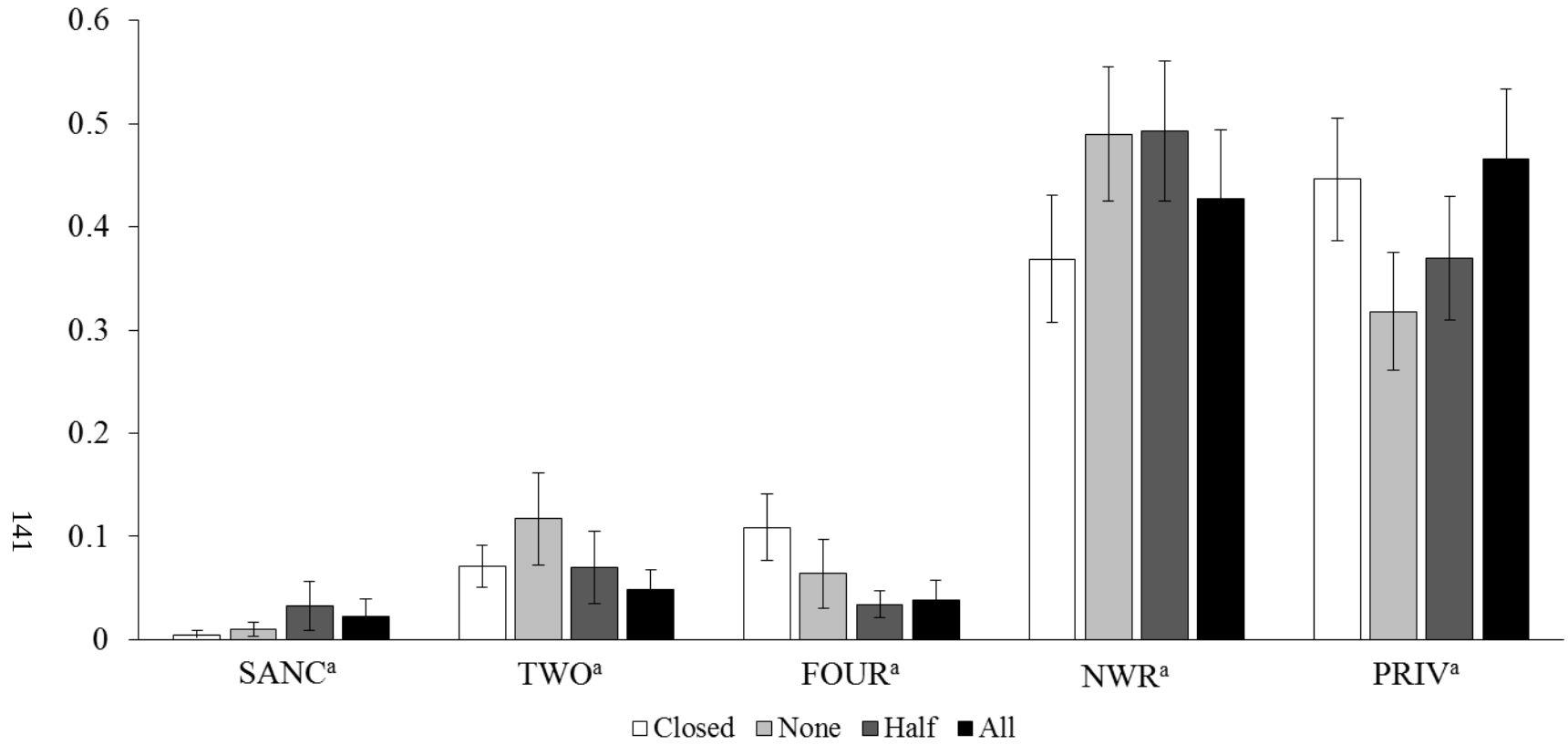

Figure 3.5 Mean use (± SE) of Muscadine Wildlife Management Area units under variable hunt management regimes, private lands, and Yazoo National Wildlife Refuge

[a] SANC = non-hunted sanctuary portion of the Wildlife Management Area. TWO = portion of the WMA hunted 2 days/week. FOUR = portion of the WMA hunted 4 days/week. NWR = Yazoo National Wildlife Refuge. PRIV = private lands.

For female mallards radio-marked at Muscadine WMA in the south Mississippi Alluvial Valley of Mississippi during winters 2010-2011 and 2011-2012.

Figure 3.6 Sanctuary (dark gray) locations relative to hunted units (light gray) at Muscadine Farms Wildlife Management area in the south Mississippi Alluvial Valley of Mississippi.

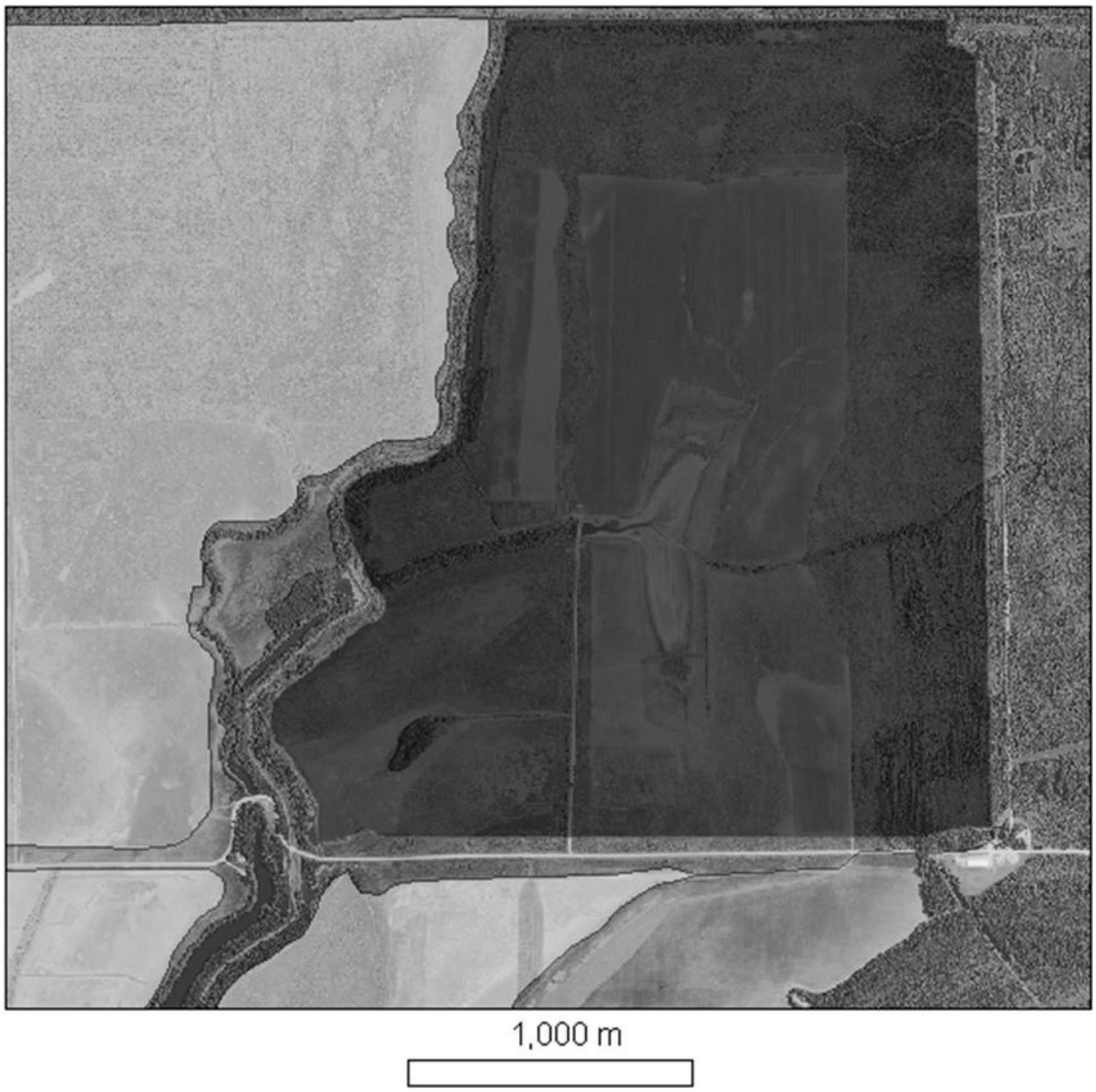

Figure 3.7 Sanctuary (dark gray) location relative to hunted units (light gray) at Mahannah Wildlife Management area in the south Mississippi Alluvial Valley of Mississippi.

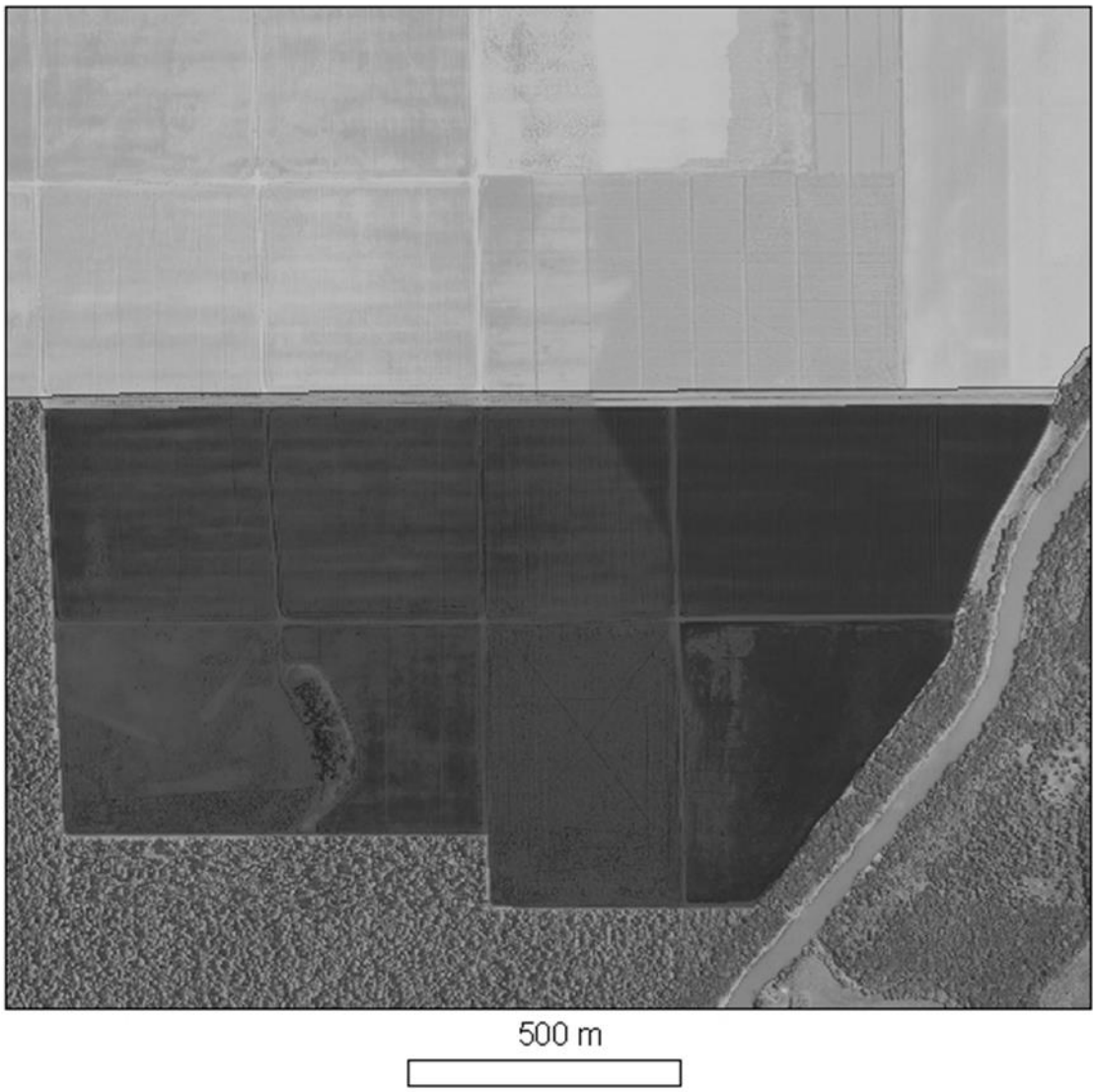

Figure 3.8 Sanctuary (dark gray) location relative to hunted units (light gray) at Howard Miller Wildlife Management area in the south Mississippi Alluvial Valley of Mississippi.

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