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I am submitting herewith a thesis written by Joshua Matthew Osborn entitled "American Black Duck Wintering Dynamics and Dabbling Duck Response to Herbicide Application in Western Tennessee Wetlands." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

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(Original signatures are on file with official student records.)

American Black Duck Wintering Dynamics and Dabbling Duck Response to Herbicide Application in Western Tennessee Wetlands

A Thesis Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Joshua Matthew Osborn
August 2015

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DEDICATION

For Mamaw Edra and Papaw Billy. If ever God created two more caring, selfless people, surely He did so by luck.

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ABSTRACT

American black duck (*Anas rubripes*) populations declined throughout North America in the late 20th century. Although the breeding population has since stabilized, research investigating habitat use by black ducks in the Mississippi Flyway is scarce. Impacts of wetland management practices in response to invasive species must also be tested to measure responses to habitat quality by black ducks and other waterfowl. During winters 2011–2013 (December–February), I estimated food biomass, diurnal habitat use, and activities of black ducks in 6 cover types at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge in western Tennessee. I also evaluated vegetation response, dabbling duck use and activities, and food biomass in moist-soil wetland plots containing alligatorweed (*Alternanthera philoxeroides*) treated with imazapyr. Black ducks were most common in scrub-shrub wetlands, where locomotion and resting behaviors were dominant activities. Although highly variable, black duck use was also high in unharvested, flooded corn. Moist-soil wetlands and mudflats were important foraging substrates, but black duck use in these areas were not equivocal to use in scrub-shrub. Greatest food biomass occurred in moist-soil wetlands compared to other cover types. However, black ducks appeared to select sites with lesser, but consistent food densities throughout winter. Waterfowl use, behavior, and food biomass did not differ between control and treatment plots. Reductions of alligatorweed with imazapyr in moist-soil wetlands did not improve use of those sites by black ducks perhaps due to a lack of shrub cover. My results suggest cumulative life-history strategies likely influence habitat use by wintering American black ducks. Managers should provide foraging areas proximate to scrub-shrub wetlands to benefit black ducks in western Tennessee. Flooded agriculture at TNWR and CCNWR could

facilitate interactions and consequently hybridization potential between mallards and black ducks. Managers should reduce flooded corn acreage and restore scrub-shrub wetlands amidst early succession emergent wetlands. Imazapyr treatment should not replace current management strategies in moist-soil wetlands (i.e., rotational disking, disking with supplemental planting, prescribed burning), but may be used to control invasive plant species as needed without negative implications on food resources for wintering waterfowl during treatment years.

TABLE OF CONTENTS

CHAPTER I: INTRODUCTION....1
LITERATURE CITED....11

CHAPTER II: HABITAT USE AND ACTIVITIES OF NON-BREEDING AMERICAN BLACK DUCKS IN WESTERN TENNESSEE....25
ABSTRACT....27
INTRODUCTION....29
STUDY AREA....30
METHODS....30
Experimental Design....30
Black Duck Surveys....31
Mobile Plots....33
Seed, Tuber, and Invertebrate Biomass....34
Habitat Availability....37
STATISTICAL ANALYSES....38
Black Duck Density....38
Seed, Tuber, and Invertebrate Biomass....40
Black Duck Activities....41
RESULTS....42
Black Duck Abundance....42
Seed, Tuber, and Invertebrate Biomass....43
Black Duck Activities....44
DISCUSSION....44
MANAGEMENT IMPLICATIONS....50
LITERATURE CITED....53
APPENDIX A: TABLES AND FIGURES....73

CHAPTER III: VEGETATION AND DABBLING DUCK RESPONSE TO IMAZAPYR TREATMENT OF ALLIGATORWEED (*ALTERNANTHERA PHILOXEROIDES)* IN WESTERN TENNESSEE....85
ABSTRACT....86
INTRODUCTION....87
STUDY AREA....89
METHODS....90
Experimental Design....90
Vegetation Response....91
Waterfowl Use and Activity....91
Seed, Tuber, and Invertebrate Biomass....92
STATISTICAL ANALYSES....94
Vegetation Response....94
Waterfowl Use and Activity....95
Seed, Tuber, and Invertebrate Biomass....96

RESULTS 97
Vegetation Response.....97
Waterfowl Density.....98
Seed, Tuber, and Invertebrate Biomass 99
DISCUSSION.....99
MANAGEMENT IMPLICATIONS 104
LITERATURE CITED 106
APPENDIX B: TABLES AND FIGURES.....120

CHAPTER IV: EXECUTIVE SUMMARY 127
LITERATURE CITED 133

APPENDIX C: TABLES AND FIGURES.....142

LIST OF TABLES

Table 1.1. Characteristics of six common cover types available to American black ducks during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.....74

Table 1.2. Mean availability of six cover types and proportions of total habitat availability of each during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.....75

Table 1.3. Percentage of surveys during which American black ducks were encountered during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.....76

Table 1.4. Odds ratios, confidence intervals, and Wald χ^2 statistics for logistic regression model that best predicted relative habitat use by American black ducks among cover types and months during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA....77

Table 1.5. Marginal effects, observed and predicted probabilities, and associated standard errors for final logistic regression model of habitat use by American black ducks at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge during December–February 2011–2013. 78

Table 1.6. Mean biomass (kg[dry]/ha) and comparisons of foods apparently consumed by waterfowl and recovered from soil and aquatic samples taken in mobile plots during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.....79

Table 1.7. Mean biomass (kg[dry]/ha) of foods apparently consumed by waterfowl recovered from soil and aquatic samples taken in fixed sites ($n \leq 4$) during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA 80

Table 1.8. Estimated Duck Energy Days (DEDs) among sites recently used (< 1 day) by American black ducks during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.. 81

Table 1.9 Activity budgets of American black ducks among six cover types during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.....82

Table 1.10. Proportions of time engaged in seven activities by American black ducks and comparisons among months during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA 83

Table 1.11. Densities (ducks/ha) of American black ducks among cover types during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA 84

Table 2.1. Biomass estimates (kg[dry]/ha) and comparisons of foods apparently consumed by waterfowl in 0.5-ha plots treated with imazapyr and adjacent un-manipulated plots (control) during winters 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge, Tennessee, USA 121

Table 3.1. Seeds, tubers, and submersed aquatic vegetation (apparently consumed by waterfowl), and aquatic macroinvertebrates, their true metabolizable energy values, and references, recovered from core samples and modified Gerking box samples during November–February 2011–2013 from the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA 139

LIST OF FIGURES

Figure 2.1. Pre-treatment (July 2011) and early growing-season (July 2012) estimates of percent horizontal cover of vegetation typically consumed by waterfowl (desirable), vegetation not consumed by waterfowl (undesirable), and alligatorweed (*Alternanthera philoxeroides*) in 0.5-ha plots treated with imazapyr and adjacent un-manipulated plots (control), during treatment (2011) and post-treatment (2012) years at the Duck River Unit of Tennessee National Wildlife Refuge, Tennessee, USA 122

Figure 2.2. Post-treatment estimates (September) of percent horizontal cover of vegetation typically consumed by waterfowl (desirable), vegetation not consumed by waterfowl (undesirable), and alligatorweed (*Alternanthera philoxeroides*) in 0.5-ha plots treated with imazapyr and adjacent un-manipulated plots (control), during treatment (2011) and post-treatment (2012) years at the Duck River Unit of Tennessee National Wildlife Refuge, Tennessee, USA 123

Figure 2.3. Average vegetation height (cm) estimated in 0.5-ha plots treated with imazapyr and adjacent un-manipulated plots (control) in September of treatment (2011) and post-treatment (2012) years at the Duck River Unit of Tennessee National Wildlife Refuge, Tennessee, USA.. 124

Figure 2.4. Density of dabbling ducks averaged across the first seven weeks of surveys post-flooding in 0.5-ha plots treated with imazapyr and adjacent un-manipulated plots (control) during winters 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge, Tennessee, USA.. 125

Figure 2.5. Mean proportion of dabbling ducks engaged in foraging, locomotion, and resting during scan-sampling observations in 0.5-ha plots treated with imazapyr and adjacent, un-manipulated plots (control) during winters 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge, Tennessee, USA.. 126

Figure 3.1. Geographic locations of the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge within the Tennessee and Cumberland River watersheds. 137

Figure 3.2. Modified Gerking box sampler (a-b) and 10 cm core sampler (c) used to collect food resources during November–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA..138

CHAPTER I: INTRODUCTION

Destruction of wetlands in North America throughout the late 1900s combined with prolonged droughts in key breeding areas, severely reduced continental waterfowl populations by the mid-1980s (Heitmeyer and Fredrickson 1981). Coordinated conservation efforts began when the North American Waterfowl Management Plan (NAWMP) was initiated in 1986, with a goal of restoring waterfowl populations to levels of the mid-1970s. The NAWMP, funded in part by the North American Wetland Conservation Act (NAWCA), is a delivery mechanism for wetland and waterfowl conservation which operates through partnerships called Joint Ventures (JV). Joint Ventures preside over specific geographic regions or taxa of conservation interest and develop science-based strategies to steward waterfowl populations and habitats at desired levels (Graziano and Cross 1993, Humburg and Anderson 2014). Further, JVs engage government agencies to adjust public policy and land-use practices to benefit waterfowl populations and their stakeholders (NAWMP 2012). Thus, NAWMP remains the cornerstone for waterfowl conservation in North America.

A primary goal of the NAWMP is to identify and investigate annual cycle events of waterfowl and how they influence reproduction and recruitment (Brasher et al. 2007, NAWMP 2012). Despite long-standing recognition of the importance of breeding-ground conditions to waterfowl populations (Weller and Batt 1988, Johnson et al. 1992, Hoekman et al. 2002), mounting evidence suggested that habitat conditions on non-breeding areas influenced population processes in waterfowl communities (Heitmeyer and Fredrickson 1981, Brodsky and Weatherhead 1985, Kaminski and Gluesing 1987, Jeske et al. 1994, Devries et al. 2008). The provision of abundant and quality food to meet desired waterfowl populations on migration and wintering grounds is a primary driver of JV conservation planning (Brasher et al. 2007, NAWMP

2012). Although food arguably is among the most important resources to nonbreeding waterfowl, it may be more plausible to consider desirable habitat as those containing beneficial structure for cover (i.e., thermal, predator escape), refugia (non-hunted sites), and some reasonable proximity to other important resources (i.e., habitat complex concept; Legagneux et al. 2009, Dooley et al. 2010*a*, *b*, Pearse et al. 2012, Beatty et al. 2014). Further complications arise because habitat use by migrating and wintering waterfowl is temporally and spatially variable, especially among species with different life history needs; thus management to deliver habitat needs is challenging (Fredrickson and Taylor 1982, Fredrickson and Reid 1988). Addressing habitat use patterns among species of waterfowl at specific spatial and temporal points promotes informed management of wetland complexes for non-breeding waterfowl communities (Johnson et al. 1980, Reinecke et al. 1989, Pearse et al. 2012, Beatty et al. 2014, Kaminski and Elmberg 2014). Understanding species' needs at multiple scales could increase managers' ability to provide functional resources to attract non-breeding waterfowl.

Effective wetland management for nonbreeding waterfowl can involve many scenarios, particularly when having to consider desired species, such as dabbling or diving ducks. Typically in the midcontinent United States, wetland managers attempt to meet foraging needs of many dabbling ducks through seasonal wetland management (Low and Bellrose 1944, Fredrickson and Taylor 1982, Strader and Stinson 2005). This scenario involves flooding (fall) and draining (spring-early summer) wetland impoundments to promote early-succession plant communities and natural foods (Fredrickson and Taylor 1982, Kross et al. 2008). The frequency and intensity of management is critical to maintaining an early succession plant community because perennials or other undesirable plants will ultimately out-compete heavy seed producing annual plants in

the absence of management (Kross et al. 2008). Periodic disturbances that include burning, mowing, or disking are necessary to reset succession and increase production of beneficial plants for waterfowl (Fredrickson and Taylor 1982, Strader and Stinson 2005, Hagy and Kaminski 2012*b*, Gray et al. 2013).

Another challenge for managers in maintaining high quality wetlands is to eliminate or control invasive or persistent undesirable plants (Madsen et al. 1997, Strader and Stinson 2005). Invasive plants create monospecific stands, displacing native wetland plants and negatively impacting invertebrate diversity and density (Powers et al. 1978, Madsen et al. 1991, Holmes 2002, Douglas and O'Connor 2003). Thus, some invasive plants negatively impact food communities and wetland vegetation structure necessary to meet life history needs of non-breeding waterfowl (Keast 1984, Benedict and Hepp 2000, Allen et al. 2007).

Alligatorweed (*Alternanthera philoxeroides*) is a non-native plant that invades moist-soil wetlands in the southeastern United States (Vogt et al. 1992, Holm et al. 1997). Alligatorweed flea beetles (*Agasicles hygrophila*) have been used successfully to control alligatorweed where mean winter temperatures are >11.1°C, but additional control measures are needed in more northerly areas (Coulson 1977, Vogt et al. 1992). Traditional moist-soil management practices (e.g., disking) exacerbate invasion of alligatorweed by spreading the rhizomes of the plant (Fredrickson and Taylor 1982). Thus, herbicide application may be requisite to manage alligatorweed and similar invasive species. Several herbicide treatments have been used to control alligatorweed with varied success (Bowmer et al. 1993, Tucker 1994, Allen et al. 2007). However, further research investigating the efficacy of herbicide treatment in controlling

alligatorweed as well as vegetation and waterfowl community response in treated wetlands is needed (Bowmer et al. 1989, Bowmer et al. 1993, Tucker 1994, Kay 1999).

Habitat quality is quantified by estimating energetic carrying capacity (Brasher et al. 2007, Hagy and Kaminski 2012*b*) and expressed in duck energy days (DED). A DED is the energy required to sustain one average-sized, free-ranging duck for one day (Bellrose 1980, Prince 1979). Energy requirements may be an important factor in regulating waterfowl populations (Brodsky and Weatherhead 1985, Plattner et al. 2010, NAWMP 2012). Thermoregulation, body maintenance, survival, feather growth, and courtship are some of the critical biological processes linked to energy requirements of waterfowl during non-breeding periods (Brodsky and Weatherhead 1984, Jorde et al. 1984, Paulus 1984*a*,*b*). Lost, fragmented, or severely impacted wetlands have made carrying capacity estimates particularly important, especially in areas that support highly specialized species like American black ducks (*Anas rubripes*). An understanding of waterfowl food selection is necessary to confidently estimate energetic carrying capacity (NAWMP 2012, Greer et al. 2009) and habitat requirements necessary for efficient waterfowl habitat management and conservation planning (Callicutt et al. 2011, Hagy and Kaminski 2012*a*).

The American black duck (hereafter, black duck) was once the most abundant waterfowl species in North America with a range that extended over the eastern third of the United States (Longcore et al. 2000). Mid-winter Waterfowl Surveys (MWS), which began in 1955, estimated 750,000 black ducks in eastern North America, with 75% and 25% occurring in the Atlantic and Mississippi Flyways, respectively. Over the next four decades however, black ducks suffered precipitous declines throughout their range, and the most recent MWS index (2014) for black

ducks was 288,800 (Rusch et al. 1989, Conroy et al. 2002, USFWSCWS 2004, Devers and Collins 2011, USFWS 2014*a*).

Harvest and management of black ducks historically have been based on MWS (Conroy et al. 1989, Diefenbach et al. 1988). However, inconsistent coverage and incomplete counts may bias MWS population indices (Rusch et al. 1989, Conroy et al. 2002, Link et al. 2006, Brook et al. 2009, Soulliere et al. 2013, USFWS 2014*a*). To alleviate bias of indices and provide more accurate estimates of black duck populations, the traditional Breeding Waterfowl and Habitat Survey was expanded in 1990 to include aerial transect surveys for breeding waterfowl populations (BPOP) in the eastern survey area, an area important for breeding black ducks. Since 2005, hierarchical models have been used which incorporate expanded BPOP data from Canadian Wildlife Service (CWS) and U.S. Fish and Wildlife Service (USFWS) aerial surveys and yield robust black duck population trends (Zimmerman et al. 2012, USFWS 2014*a*, Zimpfer et al. 2014). Data from surveys in the eastern survey area indicate 618,700 (90% CI: 552,100; 699,100) in 2014, similar to the 1990–2013 average (623,000; USFWS 2014*a*, Zimpfer et al. 2014).

Population trends of American black ducks on both breeding and wintering areas vary between the Mississippi and Atlantic Flyways. Declines continue in the Mississippi and southern Atlantic Flyways, but populations have stabilized or are slightly increasing in the central and northeast regions of the Atlantic Flyway (Link et al. 2006, Brook et al. 2009, Zimmerman et al. 2012). Declines in Mississippi Flyway black ducks during MWS have been most pronounced, decreasing from 178,400 to 19,700 (89%) between 1955 and 2014. Atlantic Flyway black ducks

declined from 582,453 to 269,000 (54%) during the same period (Fronczak 2012, USFWS 2014*a*).

Discussions of factors potentially responsible for black duck population declines have been contentious for decades (Rusch et al. 1989, Conroy et al. 2002). The most implicated, and consequently, debated factors include competition and introgressive hybridization with mallards (*Anas platyrhynchos*), harvest and hunting-related mortality, and loss or degradation of wintering and breeding habitat (Rusch et al. 1989, Conroy et al. 2002). Mallards and black ducks, the most genetically similar avian species, are believed to have speciated when receding glaciers spatially isolated two portions of a population of a parent species (Avise et al 1990, Mank et al. 2004). Extensive landscape changes via deforestation, conversion to agriculture, and anthropogenic encroachment permitted expansion of the mallard range further eastward in North America and severed genetic isolation between the two species (Johnsgard 1967, Heusmann 1974, Johnsgard and DiSilvestro 1976). Currently mallards thrive in much of the black duck's range, resulting in concerns over competitive exclusion and acquisition of suitable habitat and mates by black ducks (Brodsky and Weatherhead 1984, Brodsky et al. 1988, Merendino et al. 1993, Maisonneuve et al. 2006). Research investigating competitive exclusion and introgressive hybridization between mallards and black ducks have had varied results, and impact of these factors on black duck populations remain unclear (Conroy et al. 1989, Dwyer and Baldassare 1993, Morton 1998, Mank et al. 2004, McAuley et al. 2004, Petrie et al. 2012).

Black duck declines have also been attributed to harvest and hunter-related disturbances (Feierabend 1984). A lawsuit filed against USFWS in 1983, while failing to close hunting seasons for black ducks, prompted conservative harvest restrictions (Feierabend 1984, Francis

1998). Current literature includes support for both additive and compensatory mortality; thus uncertainty remains as to whether harvest restrictions benefit black duck populations (Krementz et al. 1987, 1988, Longcore et al. 2000, Zimpfer 2014). In recent years, an adaptive harvest management strategy has been implemented and considers two hypotheses for factors limiting population growth of black ducks: 1) additive hunting mortality and 2) competition with mallards during the breeding season (USFWS 2014*b*).

Habitat conditions influence waterfowl populations throughout the annual life cycle (Brodsky and Weatherhead 1985, Kaminski and Gluesing 1987, Prince et al. 1992, Jeske et al. 1994, Bethke and Nudds 1995, Devries et al. 2008). Loss or degradation of high-quality habitat during both breeding and non-breeding periods may negatively impact black duck populations (Rusch et al. 1989, Conroy et al. 2002). Morton et al. (1989) suggested wetland quality is more important for migrating and wintering black ducks than wetland quantity. Habitat degradation and loss in areas important to black ducks have occurred through clearing of land for agriculture (Maisonneuve et al. 2006), erosion of coastal areas (Erwin et al. 2011), channelization of rivers, and urban development (Dahl 2011). Often this results in low densities of available food resources (Steckel et al. 2003, Plattner et al. 2010, Cramer et al. 2012) and high contaminant loads (Silver and Nudds 1995) and further exacerbates declines of black ducks.

Recent evidence suggests that greater declines of black ducks in the Mississippi Flyway and western portions of BPOP and MWS reflect a range shift to the northeast (Brook et al. 2009, Devers and Collins 2011, Lavretsky et al. 2014). Christmas Bird Count (CBC) data from 1966–2003, combined with MWS data confirm species declines in central and western bird conservation regions and stable or slightly increasing abundances in northeastern regions (Link

et al. 2006). Brook et al. (2009) noted that when black ducks in MWS decreased, counts along Lake Ontario and the St. Lawrence River increased. Further, Lavretsky et al. (2014) suggested that Mississippi Flyway black ducks exhibit weaker site fidelity to wintering grounds than their Atlantic Flyway counterparts. Combined, these studies provide support for changing migration phenology and potential winter range shift in Mississippi Flyway black ducks (Link et al. 2006, Brook et al. 2009, Lavretsky et al. 2014).

Declines in the Mississippi Flyway have been the most pronounced. Approximately 30% of black ducks observed in MWS during 1955–2000, occurred in the Mississippi Flyway. During the following years, 2001–2014, the Mississippi Flyway accounted for only 10% of the continental black duck population (USFWS 2014*a*). Tennessee historically winters approximately 35% of the black duck population in the Mississippi Flyway (USFWS 2014*a*). Within the state, Tennessee and Cross Creeks National Wildlife Refuges historically winter the most black ducks (Sanders 1995). However, black ducks wintering on TNWR have declined from approximately 20,000 in 1964, a number higher than the current estimated MS Flyway population, to 5,262 (USFWS 2014*a*; R. Wheat, USFWS, unpublished data).

Research on black ducks has been extensive in North America. However, most research has focused on black ducks in the Atlantic Flyway (Conroy et al. 1989, Plattner et al. 2010, Cramer et al. 2012). Despite the importance of Tennessee, Ohio, and other areas to wintering black ducks, published information investigating their winter habits is scarce in the Mississippi Flyway (Rusch et al. 1989, Conroy et al. 2002). Chipley (1995) and Newcomb (2014) investigated habitat selection and survival rates of black ducks at TNWR during 1990–1992 and 2010–2012, respectively. Both studies noted high survival rates and selection of palustrine

emergent wetlands. Chipley (1995) also suggested avoidance of agricultural areas by black ducks. Additionally, Byrd (1991) and White et al. (1993) examined diets of black ducks in Tennessee. They reported mostly plant material (e.g., seeds, tubers, and vegetation) in diets, likely due to greater availability in interior wetlands. White (1994) also reported that black ducks used open water extensively and foraged in moist-soil areas near levees. None of these studies incorporated food availability for comparisons with diet, habitat use, or activities. Contemporary research that investigates habitat use, activities, and available food for Mississippi Flyway black ducks is needed.

The objectives of my study were (1) to investigate habitat use, potential predictors, and activities of black ducks wintering in western Tennessee (Chapter II), and (2) to examine the impacts of imazapyr-treatment on vegetation communities, dabbling duck use, and food densities (Chapter III). Results from my study will inform biologists and Joint Ventures of potential conservation strategies and areas of significant importance for interior-wintering black ducks. Further, my results will help improve wetland management with regards to invasive plant species in non-breeding areas of the Mississippi Flyway.

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CHAPTER II: HABITAT USE AND ACTIVITIES OF NON-BREEDING AMERICAN BLACK DUCKS IN WESTERN TENNESSEE

ABSTRACT

American black duck (*Anas rubripes*) populations declined throughout North America in the late 20th century. Although the breeding population has since stabilized, research investigating habitat use by black ducks in the Mississippi Flyway, an area where populations continue to decline, is scarce. During winters 2011–2013 (November–February), I estimated food biomass, diurnal habitat use, and activities of black ducks in 6 cover types at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge in western Tennessee. Black duck likelihood of use was greatest scrub-shrub wetlands, where locomotion and resting behaviors were dominant activities. Although highly variable and inconsistent over time, black duck use was also high in unharvested, flooded corn. Moist-soil wetlands and mudflats were important foraging substrates, although black duck use in these areas was not equivocal to use in scrub-shrub. Greatest food biomass was in moist-soil wetlands compared to other cover types. Flooded corn also provided considerable food energy for black ducks as evident by grain yields and significant foraging effort. My results suggest a complex of wetland types may be necessary to meet the needs of non-breeding black ducks in western Tennessee. Black ducks used scrub-shrub and SAV sites more often than moist-soil wetlands, yet these latter habitats contained greater density of food available to black ducks. Black ducks foraged in flooded corn but use was variable and inconsistent over time. Further, provision of flooded corn on these refuges may heighten interactions and potential hybridization between mallards and black ducks, as mallards are well known to consume a variety of waste agricultural seeds. Thus, in areas of management concern for wintering black ducks, flooded corn should be reduced and restored to seasonally flooded scrub-shrub wetlands amidst early succession moist-soil wetlands. Further exploration of

existing data of habitat quality models to benefit wintering black ducks in western Tennessee is warranted.

INTRODUCTION

Bioenergetic models are useful for understanding and estimating energetic carrying capacity and assessing management strategies in regions used by migrating and wintering waterfowl (Brasher et al. 2007, Bishop and Vrtiska 2008, Straub et al. 2012, Kross et al. 2008, Hagy and Kaminski 2012*b*, Williams et al. 2014). Waterfowl activity budgets may be used in conjunction with energetic models to increase understanding of nutrient requirements, energy acquisition, and energetic costs to birds in specific wetland types (Paulus 1988*a*,*b*). Thus, niche partitioning among and use of specific cover types is important for consideration of energetic dynamics and subsequent habitat management to meet needs of waterfowl populations or individual species. Further, these data may help explain behavioral strategies and habitat choices by nonbreeding waterfowl and guide future management efforts toward specific areas or cover types important in critical wintering areas of black ducks (BDJV 2008).

Wetlands have been transformed and significantly reduced in the southeastern United States (Johnson 2007, Dahl 2011). Effects of habitat loss and degradation may be more pronounced in specialists, particularly when habitat availability is severely limited or fragmented (Hannon and Schmiegelow 2002, Schmiegelow and Monkkonen 2002). For instance, forested wetlands, which are important to American black ducks (*Anas rubripes*, hereafter black ducks; Rusch et al. 1989), decreased more than 40% from 1950 to 2009 (Dahl 2011). Meanwhile, Mid-winter Waterfowl Surveys (hereafter, MWS) coordinated by the United States Fish and Wildlife

Service (USFWS) during 1955–2014 indicate a >50% decline in continental black duck counts, whereas mallards (*Anas platyrhynchos*) and other generalists have remained stable or increased despite human-induced landscape changes (Heitmeyer 2006, USFWS 2014*b*). Understanding resource use and selection by declining specialists like black ducks, can aid managers in establishing more impactful schemes to meet needs of wintering waterfowl.

Although population declines were significant between the 1950s and 1990s (Conroy et al. 2002, Devers and Collins 2011, Klimstra and Padding 2013), more recent estimates of breeding black ducks from core breeding areas in eastern Canada suggest black ducks have stabilized or are slightly increasing (USFWS 2014*b*). For Mississippi Flyway black ducks, estimates during MWS declined from approximately 87,000 in 1990 to 19,700 in 2014. During this same period, Atlantic Flyway black ducks increased from 228,749 to 269,000 (Fronczak 2012, Klimstra and Padding 2013, USFWS 2014*b*). Most contemporary research on black ducks has sought to identify factors responsible for purported declines, focusing on Atlantic Flyway populations (Conroy et al. 2002, Plattner et al. 2010, Cramer et al. 2012). Several competing hypotheses relative to black duck declines have been forwarded, including loss of quantity and quality of wintering habitat (Rusch et al. 1989, Nudds et al. 1996, Conroy et al. 2002), competition and introgressive hybridization with mallards (Ankney et al. 1987, Conroy et al. 1989*a*,*b*, Morton 1998, Mank et al. 2004, Petrie et al. 2012), and overharvest (Blandin 1982, Krementz et al. 1987, 1988). Further, a change in winter distributions of black ducks has been suggested as a contributor to disparities in population trends between the Atlantic and Mississippi Flyways (Link et al. 2006, Brook et al. 2009, LaVretsky et al. 2014).

Tennessee historically winters more than 35% of black ducks in the MS Flyway, with 75% of those occurring on either Tennessee or Cross Creeks National Wildlife Refuges (TNWR, CCNWR; Sanders 1995, USFWS 2014*a*). Wetland loss in Tennessee via urban sprawl, agricultural expansion, and river channelization has been severe (>60%, Johnson 2007). Habitat loss and degradation is most pronounced in western Tennessee, which could negatively affect black duck habitat (Johnson 2007, USFWS 2014*a*). Despite the importance of TNWR, CCNWR, other associated sites in Tennessee and wetlands of the Ohio River valley to wintering black ducks, few studies have examined habitat use of the species in the Mississippi Flyway (Rusch et al. 1989, Byrd 1991, White et al. 1993, Chipley 1995, Clark 1996, Sanders 1995, Conroy et al. 2002, Newcomb 2014). My goal was to observe habitat-specific activity budgets and estimate food availability on two important refuges for interior black ducks at the terminus of their winter migration. Ultimately, identifying and promoting resources important to black ducks during winter could guide management efforts directed at restoring the Mississippi Flyway black duck population to BDJV goals. Specifically, the objectives of my study were (1) estimate and compare proportional habitat use among six definable cover types (Table 1.1) available to interior wintering black ducks, (2) examine differences in black duck activities among six cover types, and (3) investigate differences in food availability in black duck use-sites vs. random sites in western Tennessee.

STUDY AREA

During mid-November−late February 2011–2013, I estimated black duck habitat use, activities, and available food densities on the Duck River Unit (DRU) of TNWR and CCNWR in western Tennessee (Figure 3.1). As many as 200,000 waterfowl typically winter on these refuges, with

peaks reaching 320,000 (White et al. 1993; USFWS 2010, 2014*a*). The DRU covers 10,820 ha (26,736 acres) and is located at the confluence of the Tennessee and Duck Rivers in Benton and Humphreys Counties. The CCNWR spans 3,586 ha (8,861 acres) adjacent to the Cumberland River in Stewart County. The DRU and CCNWR are managed specifically to provide sanctuary to wintering and migrating waterfowl and other waterbirds, with black ducks as a focal species. Limited hunting opportunities exist during early resident Canada goose (*Branta canadensis*) season in September, otherwise waterfowl hunting is prohibited and vehicular and foot access is restricted from 15 November to 15 March each year.

As much 35% of the interior black duck population winters on the DRU and CCNWR (Sanders 1995). Refuge biologists use intensive management practices (water-level control, disking, herbicide control of invasive and undesirable plants, and agricultural production) to provide high-quality habitat to wintering waterbirds. Management is focused on moist-soil wetlands, agricultural grains, and resources associated with riverine systems (i.e., mudflats, scrub-shrub, and lentic waters with submersed and floating aquatic vegetation; USFWS 2010, 2014*a*).

METHODS

Experimental Design

I estimated food density, habitat use, and black duck activities in six cover types available throughout the DRU and CCNWR (i.e., open water, submersed aquatic vegetation, mudflats, moist-soil wetlands, scrub-shrub, and unharvested, manipulated corn fields; Table 1.1). Prior to each field season, I selected sites (n = 4/refuge) of each cover type (hereafter, fixed-sites) based on the following criterion: 1) area of sufficient size to justify comparison of habitat use to infer

third-order selection (≥ 0.5-ha; Johnson 1980, Kaminski and Weller 1992, Kaminski et al. 1993); 2) separation by ≥ 200 m to ensure spatial independence (Kaminski et al. 1993); 3) availability on refuges; and 4) surrounding landscape that provided vantage point for cryptic observation of black ducks.

I sampled food resources and black duck behavior in each fixed site and in areas that were known sites of recent (< 1 week) black duck use (hereafter, mobile plots) monthly throughout the DRU and CCNWR. I determined areas used by black ducks from personal observations, locations of radio-marked birds from a concurrent study (Newcomb 2014), and USFWS aerial surveys. I sampled from 9 November–24 February 2011–2013 and assumed this represented the major wintering and migrating period for black ducks in western Tennessee, which is supported by aerial survey data from TNWR and CCNWR.

Black Duck Surveys

During winters 2011–2013, I estimated black duck abundance and recorded bird activities once weekly at fixed-sites at both refuges. I conducted observations from permanent elevated and ground blinds between sunrise and 5 hours after sunrise (Moon and Haukos 2008, Hagy and Kaminski 2012b). I surveyed sites along pre-determined daily routes and rotated routes weekly among observers. When logistics allowed, I systematically rotated order of sites within routes weekly to avoid potential bias associated with diurnal bird movements (Davis and Smith 1998, Anderson and Smith 1999, Moon and Haukos 2008, Greer et al. 2009).

Visual aids at known intervals can help reduce bias associated with ocular estimates of distance (Buckland et al. 2001). Prior to flooding, I placed white polyvinyl chloride (pvc) markers at 100 m and 200 m intervals from each observation blind to assist observers with

estimating distances. In open water and mudflats, I referenced known distances of fixed objects from observation points within each site to assist with distance estimates. Further, I used range finders to estimate distance intervals where not previously known (i.e., mobile plots; Buckland et al. 2001). Observers practiced detection and distance estimation together in both years prior to beginning surveys and recorded distances to the nearest 10 m.

Immediately after flooding (>60% of a fixed site flooded with surface water) in late fall, I systematically measured water depths at 10 locations along each of two randomly placed transects in each fixed-site. Using the mean water depth of random transects, I erected a water depth gauge in each plot near the observation blind. Water depth was recorded at each site during weekly surveys (Hagy and Kaminski 2012*b*). I did not erect water depth gauges in open water, mudflat, or SAV sites because they were either always deep (>45 cm) or fluctuating riverine conditions did not permit establishment of a mean depth (e.g., mudflats).

I identified, enumerated by distance, and described activities of black ducks at each site using a Swarovski® spotting scope (model STS-80; 20 × 60 magnification) or Leupold® binoculars (Acadia; 10 × 42 magnification). Upon entering an observation blind, I waited approximately 5 minutes to begin the survey and recorded mean water depth and an ocular estimate of percent emergent vegetation cover. I then surveyed a 180° semi-circle around each observation blind and included all black ducks within a range ≤200 m (Bolduc and Afton 2004, Wirwa 2009). In open water and mudflats, I sampled black ducks to a distance where identification was no longer reliable, which did not exceed 800 m (Smith et al. 1995, Laux 2008). I recorded and grouped activities into 7 categories: maintenance (i.e., preening and stretching), locomotion (i.e., flying, swimming, and walking), foraging, inactive (i.e., at rest and

sleeping), courtship, agonistic, and alert (Paulus 1984*a,b*, Morton et al. 1989*b*, Davis and Smith 1998, Eichholz et al. 2009). I did not record birds in flight during surveys.

At each fixed site, I collected continuous one-minute activity budgets on up to five black ducks. I randomly selected individuals by placing the spotting scope or binoculars at midpoint of the surveyable area and, scanning from left to right, recorded activities for the first five blacks ducks encountered. Individuals were observed for one continuous minute and their activities and duration of those activities recorded using the aforementioned seven behaviors.

Mobile Plots

At the end of each month, I sampled black duck activities in mobile plots throughout the DRU and CCNWR (i.e., both within and outside of fixed-sites). I estimated black duck abundances and recorded activity budgets in mobile plots monthly using methods similar to those described previously. I conducted observations diurnally from permanent elevated and ground blinds, automobiles, levees, or other accessible locations, which permitted inconspicuous observers a clear view, without disturbing black ducks. I included all individuals out to a distance where identification was no longer reliable, which did not exceed 800 m (Smith et al. 1995, Laux 2008). Individuals or groups separated by ≥200 m were considered to be spatially independent and surveyed separately. Similar to fixed-sites, I classified mobile plots into six cover types.

Several previous researchers have suggested that diurnal and nocturnal waterfowl behavior is similar (Albright et al. 1983, Adair et al. 1996, Brasher 2007), whereas others have documented differences (Paulus 1984*a,b*, Paulus 1988*a*, Bergan et al. 1989, Henson and Cooper 1994, Jones et al. 2014). Nocturnal foraging of black ducks has been suggested as a behavioral response to diurnal disturbance (Costanzo 1988, Morton et al. 1989*a,b*, Jones et al . 2014) and

temperature (Albright et al. 1983, Brodsky and Weatherhead 1985, Jorde 1984, Jones et al. 2014); however, I was unable to conduct nocturnal surveys because of dense vegetation in survey areas, distances between survey locations and use areas, and logistical constraints. Because I surveyed birds in a sanctuary where human disturbance was minimized and previous evidence for nocturnal waterfowl behavior is variable, I assumed diurnal surveys provided data representative of habitat use and activities in my study area.

Seed, Tuber, and Invertebrate Biomass

Diets of black ducks in Tennessee include plant materials (aquatic vegetation, seeds, and tubers) and animal foods (aquatic macroinvertebrates; Byrd 1991, White et al. 1993). I sampled plant and animal foods to estimate food density in all sites surveyed at DRU and CCNWR. I sampled fixed-sites immediately after flooding but before extensive use of plots by waterfowl (i.e., mid-late November) and monthly thereafter until late February when waterfowl began spring migration (Stafford et al. 2006, Kross et al. 2008, Hagy and Kaminski 2012*b*). I used a standard core sampler (10 cm depth and diameter) to collect seeds, tubers, and nektonic and benthic macroinvertebrates from all emergent and mudflat sites (Figure 3.2; i.e., moist-soil, mudflat, flooded scrub-shrubs, and flooded corn; Murkin et al. 1994, Stafford et al. 2006, Kross et al. 2008, Hagy and Kaminski 2012*b*). I used a modified Gerking box sampler (25 cm × 45 cm) to estimate floating seeds, nektonic aquatic invertebrates, and submersed aquatic vegetation in open water, SAV, and sites that became deeply inundated (>45 cm; Sychra and Adamek 2010; Figure 3.2). I did not estimate aboveground grain yields in flooded corn sites. Instead, I combine yield estimates from Benton and Humphreys counties during my study (NASS 2013) with previous

exponential decay functions for unharvested, flooded corn in the Mississippi Alluvial Valley (MAV; Nelms and Twedt 1996) to elicit discussion of food densities among cover types.

I collected five food samples monthly from all sites on DRU and CCNWR. In fixed-sites, I selected a random distance (0–25 m) to the first sample location and sampled at a predetermined fixed interval along a randomly-placed transect spanning the plot (Greer et al. 2007, Hagy and Kaminski 2012*b*). In mobile plots, I sampled food resources ≤1 day after black duck surveys. I collected the first sample at the location of the first black duck observed, then sampled at a predetermined fixed interval along a transect spanning the area where black ducks were observed (Greer et al. 2007, Hagy and Kaminski 2012*b*). Immediately following collection, I rinsed core samples through a 500-µm aperture sieve bucket to remove excess water and soil (Wildco, Inc., Buffalo, New York; Wirwa 2009) and deposited the sieved contents in a polyethylene bag. For box samples, I lowered the sampler 45 cm into the water column, clipped vegetation at the base of the sampler, and emptied contents of the sampler into a polyethylene bag. I preserved each sample in a 70% ethanol solution and stored at -10°C until laboratory processing at the University of Tennessee (Salonen and Sarvala 1985). First-year samples for open water and SAV were excluded because I did not have a box sampler.

I processed core and box samples randomly by site and month to account for potential bias associated with the duration samples were frozen. I thawed core samples and stained each with 1% rose bengal solution (≥24 hr) to facilitate detection of aquatic macroinvertebrates (Manley et al. 2004, Plattner et al. 2010). I removed excess mud and water by washing each through a series of graduated sieves (apertures 4.75 mm, 1.40 mm, and 0.3 µm; Kross et al. 2008, Hagy et al. 2011). I removed aquatic macroinvertebrates and vegetation with forceps,

enumerated and identified by order and genus respectively, oven-dried for 12–24 hours at 60°C to constant mass, and weighed to nearest 0.1 mg (Beal 1977; Godfrey and Wooten 1979, 1981; Murkin et al. 1994; Voshell 2002). I included all aquatic macroinvertebrate taxa in biomass estimation because little information exists to characterize waterfowl diets with respect to invertebrates (Callicutt et al. 2011, Hagy and Kaminski 2012*a*). Next, I added a solution of 3% hydrogen peroxide (H_2O_2) as needed to remove persistent soils in the remaining sieved contents prior to seed and tuber extraction. I recovered and air-dried sieved contents separately for 24–48 hours or until completely dried.

I extracted seeds and tubers of known or apparent foods of dabbling ducks, because inclusion of non-food items can bias energetic carrying capacity estimates (Straub et al. 2012, Hagy and Kaminski 2012*a*). I recovered seeds and tubers from large and medium sieves (# 4 and #14; hereafter, large portion), but was unable to process all small sieve portions across sites, months, and refuges due to budgetary and time constraints. To account for small seeds in core samples (≤ 1 mm retained by #50 sieve), I selected samples from 3 sites during the first month for each cover type at each refuge in each year. I then homogenized materials retained by the small sieve (# 50), separated a random one-quarter subsample by mass (hereafter, small portion; Livolsi et al. 2014), and removed all seeds and tubers. I identified and enumerated seeds and tubers by genus (Fasset 1940, Martin and Barkley 1961, Schummer et al. 2012), oven-dried seeds and tubers at 60°C for 24 hours, and recorded dry mass to nearest 0.1 mg. I multiplied mass of the subsample by four and created a small sieve adjustment factor for each cover type within each year by dividing the small seed biomass by the large seed biomass and adding one. I

multiplied large portion biomass by the corresponding small sieve adjustment factor for its cover type to estimate total food biomass per sample.

I applied size-specific correction factors to seed biomass estimates to account for sieve and recovery bias (Hagy et al. 2011) and converted estimates to duck energy days (DED) using the following equation (Reinecke et al. 1989, Gray et al. 2013):

$$DED = \frac{\sum(mass_{1,2....j} \cdot [1{,}000 \cdot TME_{1,2...j}])}{DER}$$

Where *mass* is the density (kg/ha) of the jth food taxon, *TME* is the true metabolizable energy (kcal/g) of the taxon, and *DER* is the mean daily energetic requirement among large dabbling duck species in the Mississippi Alluvial Valley (MAV; 294.35 kcal/duck/day; Reinecke et al. 1989, Gray et al. 2013). Where possible, I used published, taxon-specific TME values in DED calculations (Kaminski et al. 2003). In situations where multiple TME values existed for a specific genera, I used mean value of published TMEs within that genera. When genera-specific TME values were not available, I inferred TME using published values of similar plant species (TABLE 3.1).

Habitat Availability

Estimates of habitat availability are useful when inferring habitat use and selection. I used ArcGIS 10.1 to estimate monthly availability of cover types among study areas and years. I adjusted 2009 USFWS shapefiles with 2012 National Agricultural Imagery Program (NAIP) and ground-referenced maps monthly throughout both years (December–late February 2011–2013). Within each impoundment at DRU, I overlaid habitat shapefiles with LIDAR contour data (15 cm intervals) and recorded USFWS impoundment water gauge readings at the end of each month to estimate flooded habitat or mudflats. As impoundment water gauge data were not available at

CCNWR, I ground-referenced refuge habitat polygons similar to DRU, but used hand-delineated flooding and vegetation maps and survey-site water depth data in the place of impoundment gauge data. I overlaid hand-digitized versions of these data with Triangular Irregular Network (TIN) imagery to estimate habitat availability at the end of each month. Riverine systems make up or impact a significant portion of habitat at both TNWR and CCNWR. I estimated available habitat along river channels using hand-delineated maps, USFWS shapefiles, U.S. Army Corps of Engineers (USACE) and Tennessee Valley Authority (TVA) river gauge data, and available aerial imagery. Weekly water level fluctuations were minimal; thus, I assumed net changes in availability were minimal within each month, and estimated availability with a single elevation reading at the end of each month. Analyses comparing differences in habitat availability were conducted in a concurrent study (McClanahan 2015). I present a table of habitat availability estimates herein, and use these data to make habitat use comparisons among cover types (Table 1.2).

STATISTICAL ANALYSES

Black Duck Density

Few black ducks used fixed-sites and I was unable to use Program Distance to generate detection probabilities and densities specifically for black ducks. Thus, I used multiple covariates distance sampling (MCDS) analysis in Distance 6.0 to account for bias associated with survey distance and emergent vegetation in cover types where detectability was <100% by generating detection probabilities across similar sized dabbling ducks (e.g., mallard, gadwall) detected in each cover type. I then applied global detection probabilities to black duck abundances to generate density estimates specifically for black ducks (i.e., moist-soil and flooded corn sites; Smith et al. 1995,

Buckland et al. 2001, 2004, Alldredge et al. 2007, Marques et al. 2007, Thomas et al. 2009). Abundance data for dabbling ducks other than black ducks was collected in a concurrent study (McClanahan 2015). I assumed detection probability in sites without emergent vegetation was approximately 100% (Hagy and Kaminski 2012*b*, 2015). For the use of TNWR, CCNWR, and the BDJV, I estimated and present black duck density. However, large number of zeros for black duck abundances across surveys violated parametric assumptions of normally distributed variables and homogeneous variances (Quinn and Keough 2002, Zar 2009). Thus, I categorized black ducks as either present or absent during surveys, and used logistic regression to calculate odds of black duck presence and greatest likelihood of use among cover types and months (PROC LOGISTIC; Hosmer and Lemeshow 1989, Keating and Cherry 2004, Alldredge and Griswold 2006, SAS Institute Inc. 2008). Using scrub-shrub and December as reference variables for cover type and month, respectively, I compared odds of black duck presence in each cover type and month to odds for its associated reference variable to estimate likelihood of use.

I selected the best model based on lowest Akaike Information Criterion (AIC) score and fewest predictors. I computed goodness-of-fit tests with the Hosmer-Lemeshow test to assess fit of the model (Hosmer and Lemeshow 1989). I used emergent vegetation cover and mean water depth as categorical covariates and examined simple correlations to prevent issues of collinearity (Quinn and Keough 2006, Zar 2009). I grouped emergent vegetation cover into four levels (0-25%, 30-50%, 55-75%, 80-100%; Moon and Haukos 2008).

Seed, Tuber, and Invertebrate Biomass

I used separate mixed model analyses of variance (ANOVA, PROC MIXED; Littell et al. 2006, SAS Institute, Inc. 2008) to test for the effects of cover type on 1) plant foods (i.e., the sum of seeds, tubers, and submersed aquatic vegetation biomass) and 2) invertebrate masses (kg[dry]/ha) for black duck mobile plots at the DRU and CCNWR. I designated cover type as a fixed effect, year as a random effect, and month as a repeated measure. I performed separate ANOVAs for plant and invertebrate estimates. I did not analyze combined food biomass (i.e., combined seed, tuber, submersed aquatic vegetation, and benthic invertebrate biomass) because it was correlated with seed and tuber mass (r = 0.99, n = 187). Combined food biomass was not correlated with benthic invertebrate biomass (r = 0.17, n = 187) nor SAV biomass (r = 0.13, n = 187). I included in analyses only seeds and tubers reported as potential food for dabbling ducks (Olmstead 2010, Hagy and Kaminski 2012*a*), but included all aquatic invertebrate taxa because little information exists to characterize waterfowl diets with respect to invertebrates (Callicutt et al. 2011, Hagy and Kaminski 2012*a*). I did not test for interactions among fixed effects in mobile plot density because of insufficient sample size.

I did not analyze fixed-site food density, as it was used in a concurrent study (McClanahan 2015). However, I include those data in table form and use for food density comparisons between used and fixed sites. I tested for differences in food density (kg[dry]/ha) between fixed and mobile plots among months and cover types using mixed model repeated measures ANOVA (PROC MIXED; Littell et al. 2006, SAS Institute, Inc. 2008).

Prior to analysis, I observed boxplots and histograms of variables, variances of independent variables, and transformed food densities via natural logarithm to meet assumptions

of ANOVA (Quinn and Keough 2006, Zuur et al. 2010). I selected a significance level ($\alpha = 0.05$) prior to hypothesis testing (Quinn and Keough 2002, Littell et al. 2006, Zar 2009, Zuur et al. 2010). I estimated degrees of freedom via Kenward-Rogers in analyses involving mixed models and compared AICc scores to select covariance structures and random effects (Arnold 2010, Zuur et al. 2010). Additionally, I performed Tukey-Kramer pair-wise comparisons of means among cover types when $P < 0.05$. I calculated and present means and standard errors of untransformed data.

Black duck activities

I compared proportions of time black ducks spent in specific activities among cover types and months. Proportional data potentially violate assumptions of independence due to the unit-sum constraint (Aitchison 1986). Lack of independence can be overcome via compositional analysis (Aebischer et al. 1993), but activity data contained many zeros causing compositional procedures to inflate Type I error rates (Bingham and Brennan 2004, Badzinski and Petrie 2006). Thus, I investigated differences in black duck activities among cover types and months using multivariate analysis of variance (MANOVA; PROC GLM; Crook et al. 2009, Mason et al. 2009). I excluded courtship, agonistic, and alert proportions during analyses because they constituted ≤10% of black duck activities (Isola et al. 2000).

I pooled black duck activities across years to ensure sufficient sample size for significance testing. I selected proportion of time spent in each of 4 activities (foraging, inactive, locomotion, maintenance) as dependent variables, cover type and month as fixed effects, and refuge as a random effect. I used an arcsine-square root transformation on the proportion of time spent in maintenance to overcome violations of multivariate-normal distribution (Quinn and

Keough 2002, Zuur et al. 2010). I measured but did not include mean water depth or percent emergent vegetation coverage because they were highly correlated (r = 0.93) and both decreased model fit when included individually. I assumed surveys were independent and did not consider month as a repeated measure because surveys among months were separated temporally by 4–7 weeks and sampling areas often varied among months. I used Wilks's Lambda to evaluate statistical significance of MANOVA (Quinn and Keough 2002, Badzinski and Petrie 2006). If significant differences ($P < 0.05$) in activities among cover types or months occurred, I conducted Tukey–Kramer *post-hoc* means comparison tests using the PDIFF option of the LSMEANS statement.

RESULTS

Black Duck Habitat Use

I observed black ducks in 186 out of 910 (20.4%) weekly surveys at the DRU and CCNWR during December–February 2011–2013. Black ducks occurred in scrub-shrub (33.9%), SAV (23.2%), flooded corn (22.2%), moist-soil (19.6%), mudflat (15.5%), and open water (11.2%) surveys during my study (Table 1.3). I detected more black ducks during December surveys (27.1%) than either January (19.0%) or February (18.1%) surveys.

Final logistic regression models included cover type and month as predictors of black duck presence (AIC = 882.3, X^2 = 37.4, $P < 0.001$), and I found no significant evidence for lack of fit (X^2 = 6.42, P = 0.599; Hosmer and Lemeshow 1989). I selected scrub-shrub and December as reference levels for comparison of odds ratios for cover types and months. I observed a relationship between cover type and presence of black ducks (Wald X^2 = 33.6, $P < 0.001$) as well as month and presence of black ducks (Wald X^2 = 5.9, P = 0.032). Likelihood of use for scrub-

shrub was greater than use of mudflats (2.3X), moist-soil wetlands (2.9X), open water (4.3X), and SAV (1.7X; Table 1.4). Flooded corn was equally likely to be used as scrub-shrub wetlands (95% CI = 0.3–1.3), but highly variable and inconsistent over time ($\bar{x}$ = 0.5, SE = 0.4). Black ducks were 1.7 times more likely to be observed in December than February, but equally as likely in January when compared to December ($\bar{x}$ = 0.2, SE = 0.2, 95% CI = 0.3–1.2).

Seed, Tuber, and Invertebrate Biomass

I sampled food biomass (kg[dry]/ha) in 187 mobile plots in winters 2011–2013; I did not include data from open water sites (n = 19) because no food items were found in samples. Combined seed, tuber, and SAV biomass in black duck mobile plots differed among cover types during December–February 2011–2013 at the DRU and CCNWR ($F_{4,161}$ = 24.0, P < 0.001; Table 1.6) and was approximately 3 times greater in moist-soil than flooded scrub-shrub wetlands (t_{161} = 6.7, P < 0.001). I observed the lowest biomass in mudflats and open water, with no detectable difference between the two cover types (t_{161} = 0.8, P = 0.938). Seed, tuber, and SAV biomass from December–February 2011–2013 was not related to month ($F_{2,161}$ = 2.6, P = 0.0997) in use sites and net change was <10% when comparing sites used among months. (n = 63, SE = 3.3).

Invertebrate biomass in mobile plots differed among cover types (F = 2.8, P = 0.026 Table 1.6) and was greatest in flooded scrub-shrub ($\bar{x}$ = 26.7 kg/ha, SE = 5.3), moist soil ($\bar{x}$ = 24.9 kg/ha, SE = 5.3), and mudflats ($\bar{x}$ = 20.2 kg/ha, SE = 5.1). Invertebrate biomass was approximately 2 times less in SAV than in flooded scrub-shrub (t_{161} = 2.8, P = 0.020). Invertebrate biomass did not differ among months ($F_{2,161}$ = 0.9, P = 0.420).

Black Duck Activities

I collected 1,203 focal observations of black ducks in flooded corn (n = 86), flooded scrub-shrub (n = 424), mudflats (n = 106), moist-soil wetlands (n = 346), open water (n = 131), and submersed aquatics (n = 110). Proportion of time spent in activities varied across cover types (Wilks' $\lambda = 0.9$; $F = 5.7$, $P < 0.001$; Table 1.9) and months (Wilks' $\lambda = 1.0$, $F = 3.8$, $P = 0.002$; Table 1.10). Foraging, locomoting, and resting dominated black duck activities in all cover types (approximately 90% combined). I observed no differences in maintenance activities among cover types or months and did not include alert, courtship, or agonistic activities because they made up <10% of time-budgets among cover types.

Contrasts of least-square means indicated greater foraging in flooded corn, moist-soil wetlands, and mudflats (37.9%, 33.8%, and 33.0%, respectively), whereas black ducks foraged less in open water (3.2%) and SAV (17.5%). Black ducks spent more time at rest in open water (33.2%), but resting did not vary among other cover types (flooded corn, 22.4%; flooded scrub-shrub, 24.8%; mudflat, 27.3%; moist-soil, 24.3%; SAV, 22.0%). Locomotion, the most energetically costly behavior I observed (2.2 times resting metabolic rate; Wooley and Owen 1978), composed most of time-budgets in open water and SAV, 53.2% and 49.9%, respectively. Black ducks spent more time feeding in December (28.1%) and February (31.1%) than in January (22.3%), and a similar pattern existed for resting. Swimming made up more than one-third of time-budgets among months (36.7%) and was greatest in February (39.1%).

DISCUSSION

I observed greatest likelihood of use by black ducks in scrub-shrub wetlands. Previous studies in Tennessee noted the combined importance of scrub-shrub and emergent herbaceous wetlands but

were unable to separately compare the two cover types. Instead, these studies combined the two and attributed their selection to greater food and cover (Chipley 1995, Clark 1996, Newcomb 2014). Despite greater likelihood of use, food biomass during my study was less in scrub-shrub than moist-soil wetlands, indicating that black ducks did not always select areas of greatest food availability. Similarly SAV, another wetland type with relatively high use when compared to moist-soil wetlands, also contained much less food than scrub-shrub. Although ecologically different, scrub-shrub and SAV wetlands during my study superficially resembled ancestral habitat of black ducks, which was comprised of coastal marshes, forested riverine wetlands, and wooded swamps (Diefenbach and Owen 1989, Dwyer and Baldassarre 1994, Baldassarre 2014). Black duck use may be influenced by such visual cues or search images during habitat selection (Clark 1996), perhaps leading to disproportional use of such areas during my study.

Wetlands associated with bottomland hardwood forests of the southeast (e.g., scrub-shrub and SAV) were historically highly productive and contributed to diverse plant and animal communities (Wharton 1981, 1982). Remnants of those wetlands are sparse, less productive, and less energetically beneficial to Tennessee black ducks (King et al. 1999). Strong site fidelity (Bellrose and Crompton 1970) or a search image for scrub-shrub and SAV combined with sustained loss and degradation of these wetlands potentially contribute to black duck declines in the Mississippi Flyway. Continued use by black ducks during my study may also suggest scrub-shrub wetlands provide benefits to black ducks that I did not measure. For example, previous research has advocated that scrub-shrub wetlands provide refuge from avian predators, isolation for pairing activities, and some degree of invertebrate forage where females acquire protein during late winter (Brodsky and Weatherhead 1984, Jorde et al. 1984, Paulus 1984*b*, Foth et al.

2014). Invertebrate biomass during my study was greatest in scrub-shrub wetlands, but still low in terms of total availability for waterfowl (Gray et al. 2013).

Black ducks in the Mississippi Flyway commonly feed in moist-soil impoundments, green-tree reservoirs, bottomland hardwood forests, and flooded croplands (Reinecke et al. 1989, White et al. 1993). White et al. (1993) and Byrd (1991) suggested black ducks wintering in Tennessee feed mostly on plant material, but acknowledge that they collected only in sites where plant material dominated available food resources. Black duck diets in more coastal regions consist of a high proportion of animal matter (Lewis and Garrison 1984, Plattner et al. 2010, Cramer et al. 2012). Food biomass during my study was greater in moist-soil wetlands than other cover types. Although I did not measure aboveground estimates of unharvested corn, data from Benton, Humphreys and Stewart counties estimated corn yields of approximately 6,000 kg/ha (NASS 2013), which is similar to previous estimates at TNWR (Foster 2010). Estimates from other cover types across months were significantly less than moist-soil wetlands and grain yields in flooded corn (adjusted for decomposition; Nelms and Twedt 1996), and often less than suggested foraging thresholds for waterfowl (200kg/ha; Gray et al. 2013). Further, greatest percentage of time spent foraging occurred in moist-soil wetlands and flooded corn. Thus, these areas likely provide food energy for black ducks in Tennessee and may be important components of habitat complexes including scrub shrub and SAV wetlands.

Waterfowl often occur in greater densities where food biomass is greatest (Anderson and Ohmart 1988, Osborn and Hagy 2014). Among fixed sites, moist-soil wetlands provided an important foraging substrate, although black duck use in these areas was not equivocal to use in scrub-shrub. Additionally, if black ducks selected mobile plots based on foraging potential alone,

food biomass among cover types from fixed-sites would likely be less than those from recent mobile plots. Regardless of cover type, mobile plots consistently contained less food biomass than fixed-sites and densities were considerably less than previous studies in the Upper Mississippi River Valley and Great Lakes Regions (377–570 kg/ha; Brasher et al. 2007), MAV (496 kg/ha; Kross et al. 2008), and Illinois River Valley (691 kg/ha; Stafford et al. 2011). Consequently, black ducks may consider other variables in concert with food resources during habitat selection (Beatty 2014).

Variability of food across the landscape may explain a portion of the differences in food biomass across fixed and mobile plots (e.g., foragers *cannot* always feed in areas with the highest food availability; Connors et al. 1981). However, consistent disproportional use of mobile sites with less overall food biomass than fixed sites offers further support that use is at least partially unrelated to food densities, and other contributors (i.e., affinity to ancestral habitat, disturbance or predator avoidance, pair-bonding; Diefenbach et al. 1988, Brodsky and Weatherhead 1984, Jorde et al. 1984) may play a vital role in habitat use and selection (e.g., foragers do not always *want* to feed in areas with the greatest food availability; Abramsky et al. 2002). Food biomass remained consistent among months in mobile plots despite declining trends in fixed-site plots (McClanahan 2015). As food resources decompose or are exploited during winter, managers flood impoundments "as needed" to inundate new food resources for wintering waterfowl. Consistent food biomass in mobile plots among months is likely a result of black ducks mobilizing to exploit these newly inundated resources (Davis et al. 2009).

Consistent with previous research, foraging and locomotion were dominant behaviors in activity budgets at TNWR and CCNWR during my study (Jorde et al. 1984, Paulus 1984, Rave

and Baldassarre 1989, Mason et al. 2013). Whereas foraging was greatest in flooded corn and moist-soil wetlands, black ducks also spent significant time foraging in scrub-shrub wetlands and mudflats, two areas with considerably less food. Locomotion was most common in SAV, mudflats, and scrub-shrub, perhaps a result of searching for food resources or as a subtle pursuit of courtship not obvious to observers. Regardless, black ducks exerted significant energy in the form of swimming and exploration feeding in these areas, with minimal apparent return in the form of energy from food. Thus, despite high use and apparent affinity to these areas as suggested in this and previous studies (White 1994, Reinecke et al. 1989, Newcomb 2014), SAV and scrub-shrub wetlands may be an energetic sink for American black ducks in Tennessee.

For most waterfowl species, foraging effort is greatest in fall (August–November), least in winter (December-January), and increases in early spring (February–April; Paulus 1988*b*). I observed greatest foraging effort in February, a period during which feeding may have increased due to scarcity of food and pre-migratory hyperphagia (Tamisier 1972, Miller 1985) or to fulfill nutrient needs for upcoming egg-laying and breeding activities (Paulus 1984*b*). Locomotion was also greatest during February, perhaps also due to searching for scarce food resources. I did not observe black ducks in significant numbers during November. Black ducks tend to be strong facultative migrants (Bellrose and Crompton 1970, Baldassarre 2014) and likely arrived at DRU and CCNWR later than other dabbling ducks. Thus, the high foraging effort I witnessed in December may be because black ducks arrived later and foraged to accumulate lipid reserves for use as energy later in winter (Paulus 1980, 1983; Miller 1985). Proportion of time spent resting was greatest in January, perhaps because birds acquired lipid reserves in December and selected thermally favorable microhabitat to minimize energy losses (Brodsky and Weatherhead 1984,

Jorde et al. 1984, Paulus 1984*b*).

During a concurrent study on TNWR, Newcomb (2014) observed radio-marked black duck females selecting emergent/scrub-shrub cover in greater proportion than other cover types, further supporting greater affinity to scrub-shrub wetlands by black ducks in Tennessee. Newcomb further noted nocturnal use of emergent/scrub-shrub wetlands by black ducks at TNWR. More specifically, Chipley (1995) reported black ducks were most common and intensely foraged in emergent herbaceous wetlands nocturnally. Waterfowl may forage nocturnally to meet energy requirements that were not met diurnally (Brodsky and Weatherhead 1984*a*, Kaminski et al. 2003) or to forage on preferred foods, which are inaccessible diurnally (i.e., predator avoidance; McNeil et al. 1992, Casazza et al. 2012). Nocturnal feeding patterns may also be favored if metabolic heat produced by feeding lowers thermoregulatory cost (Calder and King 1974). The TNWR and CCNWR are waterfowl sanctuaries during winter, and human-related disturbances are minimized. Regardless, any factor which elicits nocturnal foraging by black ducks likely impacts diurnal habitat selection and activities. My results agree with those of Newcomb (2014) and Chipley (1995) and ultimately suggest a complex of wetland types may be necessary to meet the needs of non-breeding black ducks in western Tennessee (Nichols et al. 1983, Pearse et al. 2012, Gray et al. 2013). Specifically, emergent herbaceous wetlands are necessary to meet nutritional needs of black ducks in Tennessee, whereas black ducks may incur benefits from scrub-shrub wetlands not reconciled by my study.

Competition between black ducks and mallards on the breeding grounds is limited, and interactions that occur are often dominated by black ducks (Petrie et al. 2012). Similarly, competition during winter is likely negligible because dabbling ducks shift or specialize foraging

methods as foods are depleted (DuBowy 1988. Guillemain et al. 2002). However, black ducks and mallards share similar pairing chronologies and use similar cover for courtship during winter (Johnsgard 1960). Further, un-paired female black ducks often prefer to pair with male mallards, even when male black ducks are abundant (Brodsky and Weatherhead 1984). During my study, black duck habitat use overlapped with that of mallards in all cover types at TNWR and CCNWR. Mallards were present in 100% of flooded corn surveys during which black ducks were observed, whereas black ducks and mallards co-occurred in ≤50% of surveys in all other cover types. Although highly variable, black duck use in flooded corn was similar to scrub-shrub wetlands. Corn is often flooded late in winter to supplement natural foods for waterfowl, and I speculate high likelihood of use by black ducks is an artifact of this strategy. However, black duck use in flooded corn may increase interactions with mallards, who forage in large numbers in flooded corn (McClanahan 2015), consequently increasing opportunities for hybridization. Thus, consideration should be given to reducing acreage of low-lying areas sharecropped for corn and restoring these areas as seasonally flooded scrub-shrub wetlands amidst early succession moist-soil wetlands in refuges and others areas targeting conservation of black ducks during winter.

MANAGEMENT IMPLICATIONS

Results from my study suggest scrub-shrub wetlands are frequently used by black ducks wintering in western Tennessee, but likely serve as energetic sinks to black ducks and other waterfowl throughout winter. Thus, a variety of wetland types may be necessary to accommodate energetic and other life-history needs of black ducks in western Tennessee (Gray et al. 2013). For instance, emergent wetlands are important foraging areas for black ducks in Tennessee, thus

managers should consider strategies to juxtapose emergent and scrub-shrub wetlands. Managing for scrub-shrub requires allowing mid-succession plants to establish, a technique contradictory to traditional moist-soil management. However, active moist-soil management can be practiced adjacent to passively managed scrub-shrub to create the same effect. Further, areas of marginal foraging quality with surrounding cover may offer benefits to black ducks that high foraging quality wetlands with scarce or non-existent cover do not. Such strategies may decrease energy expenditure via flight, exposure to hunting pressure, and other depredation risks, while also providing critical food resources. Management of black duck habitat in Tennessee should focus on expanding or maintaining scrub-shrub wetlands, particularly in or near areas of high-quality moist-soil vegetation. Further, future habitat quality models should consider relative importance of cover metrics to spatio-temporal use of scrub-shrub and other wetlands, reconciling benefits I did not measure in my study.

I recommend altering water control strategies to increase SAV availability to non-breeding black ducks. Partial drawdowns of impoundments and pumping of excess water in areas where gravity drains over-top SAV will ensure foliage is available for full use by black ducks and other waterfowl. Such management will increase carrying capacity in SAV, a high-use area for black ducks in western Tennessee. Additional research is needed to determine energetic benefits (e.g., true metabolizable energy) of aquatic vegetation and to identify other benefits black ducks obtain from SAV areas.

Black duck behaviors during my study suggest energy is not limiting for black ducks in western Tennessee. Thus, management of flooded agricultural crops to maximize food energy may not be warranted. Further, provision of flooded corn on these refuges may heighten

interactions between mallards and black ducks, as mallards are known to consume a variety of waste agricultural seeds (Jorde et al. 1984, Baldassarre 2014, McClanahan 2015). Flooded agriculture at TNWR and CCNWR could increase interactions and facilitate potential hybridization between these two species. Therefore, in areas of critical management priority for black ducks, I recommend reducing acreage of low-lying areas sharecropped for corn and other grains and restoring these areas as seasonally flooded scrub-shrub wetlands amidst early succession moist-soil wetlands. Further exploration of existing data on mallards and black ducks (Newcomb 2014, McClanahan 2015) could refine development of habitat quality models to benefit wintering black ducks in western Tennessee.

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APPENDIX A: TABLES AND FIGURES

Table 1.1. Characteristics of six common cover types available to American black ducks during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.

Cover Type	Description
Open water	Permanently flooded areas (>45cm deep) with ≤30% horizontal cover of vegetation (unconsolidated bottom)
Submersed aquatic vegetation (SAV)	Permanently flooded areas (>45cm deep) with >30% horizontal cover of rooted or floating vascular at the time of first sampling in late autumn
Mudflats	Shallowly flooded (<45cm deep) wetlands with >30% bare soil and <30% vegetative cover (unconsolidated shore)
Moist-soil	Seasonally flooded areas with >30% horizontal cover of persistent or non-persistent herbaceous vegetation (<45cm deep)
Scrub-shrub	Narrow strips of open water mostly covered by a shrub/tree canopy on either side of the channel, narrow deep-water sloughs with flooded tree or shrub structure, or other similar habitat where water abuts tall woody vegetation creating a distinct edge
Un-harvested flooded corn	Un-harvested corn fields that have been mechanically knocked down without tilling the soil in late autumn and subsequently shallowly flooded (<45cm)

Table 1.2. Mean availability (number of hectares flooded to depth ≤45cm) of six cover types and proportion of total habitat availability of each during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.

		Un-harvested flooded corn		Scrub-shrub		Mudflats		Moist-soil		Open water		SAV	
Year	Month	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$	%
2011–2012	December	24.0	3.9	113.2	18.2	169.0	27.1	276.0	44.3	1599.4	-	41.1	6.6
	January	36.5	6.7	114.1	20.8	60.5	11.0	296.4	54.0	1651.6	-	41.1	7.5
	February	28.9	4.3	114.3	17.0	198.9	29.6	288.7	43.0	1570.4	-	40.9	6.1
	Overall	31.0	3.4	113.9	18.5	142.8	23.2	287.0	46.6	1607.1	-	41.0	6.7
2012–2013	December	10.8	2.0	150.2	27.4	47.1	8.6	172.4	31.5	1690.9	-	167.3	30.5
	January	46.6	6.7	164.3	23.5	63.6	9.1	256.9	36.7	1695.8	-	167.9	30.6
	February	43.9	6.5	164.3	24.4	85.0	12.6	257.2	38.2	1695.6	-	122.4	22.4
	Overall		5.3	159.6	24.9	65.2	10.2	228.8	35.8	1694.1	-	152.5	27.8
2011–2013	December	17.4	3.0	131.7	22.5	108.0	18.4	224.2	38.3	1645.1	-	104.2	17.8
	January	39.9	6.4	139.2	22.4	62.1	10.0	276.7	44.5	1673.7	-	104.4	16.8
	February	33.9	5.1	139.3	20.8	142.0	21.2	272.9	40.8	1633.0	-	81.7	15.4
	Overall	32.0	5.1	136.7	21.8	104.0	16.6	257.9	41.1	1650.6	-	96.7	15.4

Table 1.3. Percentage and number of surveys during which American black ducks were encountered during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.

	Overall (n = 186)		December (n = 73)		January (n = 66)		February (n = 47)	
Cover Type	*n*	%	*n*	%	*n*	%	*n*	%
Un-harvested flooded corn	10	22.2	0	0	4	22.2	6	26.1
Scrub-shrub	60	33.9	17	32.1	24	34.8	19	34.5
Mudflats	30	15.5	16	20.1	10	15.9	4	7.5
Moist-soil	28	19.6	15	35.7	7	13.0	6	12.8
Open water	22	11.2	9	12.2	6	8.3	7	13.7
Submersed aquatic vegetation	36	23.2	16	25.4	15	30.0	5	11.9

Table 1.4. Likelihood of use, odds ratios, confidence intervals and Wald χ^2 statistics for logistic regression model that best predicted relative habitat use by American black ducks among cover types and months during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.

Predictor		*n*	Likelihood of Use	Odds Ratio (%)	Confidence Interval		Wald χ^2	Pr > χ^2
Cover Type	Un-harvested flooded corn	45	-1.6	0.6	0.3	1.3	1.5	0.216
	Mudflats	193	-2.9	0.3	0.2	0.6	17.3	<.001
	Moist-soil	143	-2.1	0.5	0.3	0.82	8.1	0.004
	Open water	197	-4.3	0.2	0.1	0.4	27.1	<.001
	Submersed aquatic vegetation	155	-1.7	0.6	0.3	0.9	5.1	0.024
Month	January	293	-1.2	0.836	0.6	1.2	0.8	0.372
	February	294	-1.7	0.599	0.4	0.9	5.9	0.015

[a] Summaries are relative to reference variables scrub-shrub and December.

Table 1.5 Marginal effects, observed and predicted probabilities, and associated standard errors for final logistic regression model of habitat use by American black ducks at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge during December–February 2011–2013.

Predictor		Marginal Effects	SE	Predicted Probability	SE	Observed Probability	SE
Cover Type	Un-harvested flooded corn	7.6	0.1	22.2	0.5	22.2	6.2
	Scrub-shrub	.	.	33.9	0.4	33.9	3.6
	Mudflats	7.8	0.1	15.5	0.2	15.5	2.6
	Moist-soil	11.7	0.1	19.6	0.3	19.6	3.3
	Open Water	22.5	0.2	11.2	0.1	11.2	2.2
	Submersed aquatic vegetation (SAV)	8.8	0.1	23.2	0.3	23.2	3.4
Month	December	.	.	23.2	0.5	23.2	2.4
	January	-5.2	0.1	21.2	0.5	21.2	2.4
	February	8.8	0.1	16.7	0.4	16.7	2.1

[a] Marginal effects not listed for reference variables, scrub-shrub and December.

Table 1.6. Mean biomass (kg[dry]/ha) and comparisons[a] of foods apparently consumed by waterfowl and recovered from soil and aquatic samples taken in mobile plots during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.

		Un-harvested flooded corn (n = 2, 11, 5)		Scrub-shrub (n = 19,20,25)		Mudflats (n = 5,2,5)		Moist-soil (n = 26,19,22)		Open water (n = 5,8,6)		SAV (n = 4,3,0)	
Food Type	Month	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Seeds, Tubers, and SAV	December	74.1	4.6	96.3	17.1	8.1	3.0	354.8	60.0	0	0	39.3	35.4
	January	80.0	19.2	121.0	48.7	26.1	22.1	352.5	58.7	0	0	11.7	10.5
	February	74.8	23.1	110.7	31.7	21.8	12.0	201.2	31.5	0	0	-	-
	Overall	77.9A	12.9	109.7A	19.8	16.8B	6.0	303.7C	32.3	0	0	27.5B	20.0
Invertebrates	December	2.2	1.6	46.0	14.5	29.6	7.4	18.9	5.5	0	0	4.0	3.5
	January	12.9	6.4	13.0	4.0	3.6	2.1	21.3	6.4	0	0	0.2	0.0
	February	9.5	5.3	22.9	6.5	17.4	8.2	35.2	13.6	0	0	-	-
	Overall	10.8AB	4.1	26.7A	5.3	20.2A	5.1	24.9A	5.3	0	0	2.3B	2.0
Combined	December	76.3	3.0	142.3	27.1	37.8	9.2	373.7	60.8	0	0	43.3	38.9
	January	92.9	23.4	134.0	48.2	29.7	24.0	373.8	58.3	0	0	11.9	10.6
	February	84.3	21.1	133.7	30.0	39.2	11.9	236.4	45.0	0	0	-	-
	Overall	88.7	15.1	136.4	20.4	37.1	6.7	328.6	32.9	0	0	29.8	22.2

[a] Means in the same row but with different capital letters are significantly different ($P < 0.05$) based on Tukey-Kramer multiple pairwise comparisons of least square means. Means without letters were not included in pairwise comparisons.

Table 1.7. Mean biomass (kg[dry]/ha) of foods apparently consumed by waterfowl recovered from soil and aquatic samples taken monthly in fixed-sites ($n \leq 4$) of six cover types during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.

		Un-harvested flooded corn (n = 2, 3, 8, 8)		Scrub-shrub (n = 11,14,15,16)		Mudflats (n = 5,15,15,15)		Moist-soil (n = 11,13,14,14)		Open water (n = 7,7,8,8)		SAV (n = 7,7,7,7)	
Food Type	Month	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Seeds, Tubers, and SAV	November	4.6	2.5	164.6	82.5	16.2	3.7	683.2	136.7	0	0	26.2	13.1
	December	126.6	61.4	233.2	112.0	10.5	3.7	513.4	107.5	0	0	0.6	0.4
	January	57.6	18.2	162.8	70.3	14.6	5.3	253.8	73.7	0	0	0.4	0.2
	February	65.9	18.2	89.2	38.7	10.2	4.2	144.1	55.1	0	0	3.0	2.9
	Overall	65.6	16.3	159.7	38.6	12.9	2.1	380.0	53.7	0	0	7.5	3.8
Invertebrates	November	18.0	6.5	18.8	5.9	165.5	64.2	21.7	7.5	0	0	13.9	3.7
	December	7.5	5.5	42.1	12.3	133.9	52.4	21.7	5.9	0	0	0.2	0.1
	January	5.6	2.1	13.8	4.6	46.8	25.2	17.6	7.1	0	0	0.1	0.0
	February	6.4	3.1	32.1	9.8	34.0	23.7	11.4	3.7	0	0	0.7	0.6
	Overall	7.4	1.8	27.1	4.7	95.1	23.1	17.8	3.0	0	0	3.7	1.5
Combined	November	22.5	9.0	183.3	81.2	181.7	64.7	704.8	135.5	0	0	40.1	15.9
	December	134.1	56.1	275.3	114.0	144.5	52.1	535.0	106.0	0	0	0.8	0.5
	January	63.2	18.5	176.6	71.7	61.4	24.8	271.4	72.7	0	0	0.4	0.3
	February	72.3	31.6	121.4	38.9	44.2	23.6	155.4	56.3	0	0	3.6	3.2
	Overall	72.9	16.3	186.8	39.1	108	23.1	397.8	53.7	0	0	11.2	5

Table 1.8 Estimated duck energy days (DEDs) among sites recently used (<1 day) during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.

		Un-harvested flooded corn (n = 2, 11, 5)		Scrub-shrub (n = 19,20,25)		Mudflats (n = 5,2,5)		Moist-soil (n = 26,19,22)		Open water (n = 5,8,6)		SAV (n = 4,3,0)	
Food Type	Month	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Seeds, Tubers, and SAV	December	1880.5	394.5	1060.0	284.3	48.3	14.8	2904.9	608.8	0	0	114.9	103.6
	January	1480.6	568.6	1264.2	570.8	508.8	481.8	2798.7	568.9	0	0	37.6	33.9
	February	1984.6	627.2	1138.4	403.4	113.2	65.8	1241.9	323.1	0	0	0.0	0.0
	Overall	1642.0	403.6	1154.5	248.8	152.1	81.2	2328.7	315.0	0	0	81.8	58.9
Invertebrates	December	4.8	2.8	118.0	66.5	4.1	0.9	28.5	9.6	0	0	4.2	3.7
	January	10.8	4.5	12.8	3.5	4.1	0.9	359.7	273.5	0	0	0.2	0.1
	February	7.6	3.8	25.4	7.1	833.2	822.7	43.1	20.1	0	0	0.0	0.0
	Overall	13.5	4.8	49.0	20.4	363.6	341.9	127.2	78.5	0	0	2.4	2.2
Combined	December	1885.3	396.1	1178.1	339.4	86.2	18.7	2933.4	609.6	0	0	119.1	107.3
	January	1491.5	572.7	1277.0	570.3	512.9	482.8	3158.4	645.8	0	0	37.8	33.9
	February	1992.2	625.1	1163.9	401.5	946.5	819.4	1285.1	325.3	0	0	0.0	0.0
	Overall	1655.5	405.7	1203.4	253.9	515.7	345.5	2456.0	329.0	0	0	84.2	61.0

Table. 1.9. Proportion of time engaged in seven activities by American black ducks and comparisons[b] among six cover types during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.

	Un-harvested flooded corn (n = 86)		Scrub-shrub (n = 424)		Mudflats (n = 106)		Moist-soil (n = 346)		Open water (n = 131)		SAV (n = 110)	
Activity[a]	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Foraging	37.9A	4.3	27.2B	1.8	33.0AB	4.0	33.8AB	2.1	3.2C	1.2	17.5B	3.1
Inactive	22.4A	2.4	24.8A	1.6	27.3A	3.9	24.3A	1.7	33.2A	3.2	22.0A	3.2
Locomotion	28.1A	3.7	35.4A	1.8	28.5A	3.4	32.2A	1.8	53.2B	3.3	49.9B	3.8
Maintenance	8.5A	2.2	8.0A	0.9	8.6A	2.1	5.7A	0.8	7.0A	1.4	6.9A	1.6
Alert	2.0	0.7	1.5	0.3	1.6	0.7	1.9	0.3	1.7	0.7	2.1	0.6
Agonostic	1.3	0.8	0.5	0.2	0.3	0.2	0.4	0.1	0.5	0.2	0.1	0.1
Courtship	0.2	0.1	2.0	0.3	0.3	0.2	0.9	0.2	1.1	0.5	1.5	0.6

[a] Means represent percentage of time expended during 1-minute focal surveys.

[b] Means within rows followed by unlike capital letters indicate no significant difference ($P < 0.05$) based on Tukey-Kramer multiple pairwise comparisons test of least squares means. Means without letter groupings not included in pairwise comparisons.

Table 1.10. Proportion of time engaged in seven activities by American black ducks and comparisons[b] among months during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.

	December (n = 391)		January (n = 446)		February (n = 366)	
Activity[a]	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Foraging	28.1A	1.8	22.3B	1.7	31.1A	2.1
Inactive	25.1A	1.7	29.1B	1.7	21.2A	1.7
Locomotion	34.7A	1.8	36.3A	1.8	39.1B	2.0
Maintenance	7.3A	0.9	8.0A	0.9	6.2A	0.9
Alert	1.7	0.3	2.3	0.3	1.2	0.3
Agonostic	0.4	0.1	0.9	0.2	0.0	0.0
Courtship	0.1	0.2	1.6	0.3	1.2	0.3

[a] Means represent percentage of time expended during 1-minute focal surveys.

[b] Means within rows followed by unlike capital letters indicate no significant difference ($P < 0.05$) based on Tukey-Kramer multiple pairwise comparisons test of least squares means. Means without letter groupings not included in pairwise comparisons.

Table 1.11. Densities (ducks/ha) of American black ducks among cover types during December–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.

		Unharvested flooded corn			Scrub-shrub			Mudflats			Moist-soil			Open water			Submersed Aquatic Vegetation		
Year	Refuge	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
2011	TNWR	14	1.4	0.8	46	3.0	1.3	48	0.1	0	33	2.1	0.6	36	0	0	12	0	0
	CCNWR	9	2.2	1.7	46	1.5	0.4	36	0.9	0.4	43	0.2	0.2	48	0.2	0.1	36	0.5	0.2
	Combined	27	1.7	0.8	92	2.3	0.7	84	0.4	0.2	76	1.0	0.3	84	0.1	0	28	0.4	0.1
2012	TNWR	19	1.4	0.6	48	1.6	0.5	48	0.1	0	31	1.2	0.5	48	0	0	36	0.2	0.1
	CCNWR	0	-	-	36	1.2	0.3	48	0.5	0.2	20	0.8	0.6	36	0.1	0	36	0.7	0.3
	Combined	19	1.4	0.6	84	1.4	0.3	96	0.3	0.1	51	1.1	0.4	54	0.1	0	72	0.5	0.2

CHAPTER III: WATERFOWL AND HABITAT RESPONSES TO IMAZAPYR TREATMENT OF ALLIGATORWEED (*ALTERNANTHERA PHILOXEROIDES*) IN WESTERN TENNESSEE

ABSTRACT

Invasive species such as alligatorweed (*Alternanthera philoxeroides*) commonly grow in dense monospecific stands, outcompeting and displacing native wetland plants. Moist-soil management often involves herbicide applications to control invasive or undesirable plants and permit germination of desirable grasses and sedges for waterfowl. The impacts of herbicide treatment of invasive species on non-breeding waterfowl use and habitat quality have not been examined. Further, management implications for black ducks (*Anas rubripes*), a species experiencing population declines, have not been explored for such management practices. During winters 2011–2013 (December–February), I evaluated and compared vegetation response, black duck and other dabbling duck (Anatini) use and activities, and food biomass between moist-soil wetlands containing alligatorweed (*Alternanthera philoxeroides*) and experimentally treated with imazapyr, and adjacent un-manipulated controls at the Duck River unit of Tennessee National Wildlife Refuge. Percent cover and height of desirable vegetation were greater in control than imazapyr-treated plots during the year of treatment, but did not differ the following year. Waterfowl use, behavior, and food biomass did not differ between control and treatment plots. Similarly, reductions of alligatorweed coverage with imazapyr in moist-soil wetlands did not improve use of those sites by black ducks perhaps due to a lack of shrub cover, an important component of ancestral and contemporary habitat used by black ducks. Imazapyr treatment should not replace current management strategies to improve moist-soil wetlands (i.e. rotational disking, disking with supplemental planting, prescribed burning, etc.), but should be used to control invasive plant species and release native wetland plants.

INTRODUCTION

Moist-soil management is a strategy to promote shallowly-flooded wetlands dominated by annual plant communities that produce abundant seeds and other forage for wetland-dependent wildlife (Rundle and Fredrickson 1981, Nyman et al. 1990, Laubhan and Fredrickson 1993, Reid 1993, Parsons 2002, Gray et al. 2013). The technique uses a combination of water-level and soil manipulations to create desired plant and invertebrate communities dominated by early-successional plants that produce abundant food resources and provide cover for waterfowl in winter (Fredrickson and Taylor 1982, Gray et al. 1999, Gray et al. 2013). The use of moist-soil management expanded in the United States during the 1980s in an attempt to counteract the effect of widespread wetland loss that occurred in the 1900s, and restore waterfowl populations in migrating and wintering areas of North America (Gray et al. 2013).

Moist-soil management often involves controlling invasive or undesirable plants (Madsen et al. 1997, Strader and Stinson 2005). Invasives such as purple loosestrife (*Lythrum salicaria*), common reed (*Phragmites australis*), and alligatorweed (*Alternanthera philoxeroides*) commonly grow in dense monospecific stands that outcompete and displace native wetland plants (Powers et al. 1978, Madsen et al. 1991, Holmes 2002). Several studies have reported lesser seed and aquatic invertebrate production and waterfowl use in wetlands dominated by invasive plant species (Keast 1984, Cyr and Downing 1988, Trammel and Butler 1995, Benedict and Hepp 2000, Douglas and O'Connor 2003).

Alligatorweed is native to South America and was introduced accidentally into the United States via ship ballasts (Zeiger 1967, Vogt et al. 1979). Alligatorweed invades shallowly flooded areas prior to summer drawdowns. Collectively, new growth forms dense mats, blocks sunlight

from moist soils, reduces oxygen levels, and outcompetes desirable plant communities (Quimby and Kay 1977, Vogt et al. 1992, Buckingham 1996, Holm et al. 1997). Alligatorweed does not typically produce seed outside of its native range; thus it is not a valuable source of food for waterfowl (Holm et al. 1997).

Traditional moist-soil management practices (e.g., disking, mowing, and prescribed burning) can increase coverage of alligatorweed by mulching the plant and facilitating vegetative reproduction (Holm et al. 1997). Current methods used for control include release of biological control agents and herbicide (Selman and Vogt 1971, Vogt et al. 1992, Bowmer et al. 1993, Tucker 1994, Allen et al. 2007). Control of invasive aquatic plants with herbicides, such as glyphosate and imazapyr, is often necessary in the southeastern United States to improve desirable plant composition in seasonally-managed wetlands (Strader and Stinson 2005).

Numerous herbicides have been used to control alligatorweed with varied success. For example, glyphosate controls floating mats of alligatorweed, but does not affect its terrestrial form or submersed roots because of poor translocation. Further, glyphosate is not selective and may kill desirable wetland vegetation (Bowmer et al. 1993, Tucker 1994). 2,4-D is more selective, but requires multiple applications and complete control may not be achieved (Eggler 1953). Allen et al. (2007) suggested habitat improvement could be accomplished by applying imazapyr, a broad-spectrum herbicide that controls various annual and perennial grasses, broadleaf weeds, and woody species. Imazapyr (Habitat®, BASF, Research Triangle Park, NC 27709) is an acetolactate synthase (ALS) regulator that inhibits synthesis of branched amino acids required for protein synthesis and cell growth. Allen et al. (2007) reported use of imazapyr during July at 3.6 L ha^{-1} allowed desirable plants to establish and compete with alligatorweed,

but waterfowl response was not quantified. Few studies have investigated the effects of imazapyr application on alligatorweed in moist-soil wetlands, and none have investigated subsequent waterfowl response (Bowmer et al. 1989, Bowmer et al. 1993, Tucker 1994, Kay 1999). Thus, the objective of my study was to investigate the effects of imazapyr treatment of moist-soil wetlands on vegetation structure and quality, winter food density, and use and activities of non-breeding dabbling ducks (Anatini) in western Tennessee.

STUDY AREA

My study was conducted in experimental wetlands within the Duck River Unit (DRU) of Tennessee National Wildlife Refuge (TNWR; Figure 3.1; 10,820 ha) in western Tennessee. The TNWR is located in Benton and Humphreys Counties at the confluence of the Tennessee and Duck Rivers. The TNWR is comprised of three units (Big Sandy, Busseltown, and the DRU), with DRU being the most intensively managed. The refuge contains diverse habitat complexes, as much as 35% of black ducks detected during U.S. Fish and Wildlife Service (USFWS) Mid-winter Waterfowl Ssurveys, and provides sanctuary to as many as 200,000 wintering waterfowl. (USFWS 2010, USFWS unpublished data). Public access is limited at TNWR from 15 November to 15 March to provide sanctuary to wintering waterfowl.

The DRU consists of riverine wetlands as well as seasonally flooded moist-soil impoundments. Impoundments are flooded via precipitation, pumping from the Tennessee River, and gravity drain through multiple water-control structures throughout the main body of the refuge. The refuge manages multiple cover types as sanctuary for wintering waterfowl and management practices include water-level control; disking, herbicide, and other control of invasive and undesirable vegetation; and agricultural production (USFWS 2010).

METHODS

Experimental Design

During summer 2011, I established four paired imazapyr-treated and control plots (hereafter, blocks) in moist-soil wetlands at the DRU based on the following criteria: 1) presence of alligatorweed; 2) area of sufficient size to justify comparison of habitat use to infer third-order selection (≥ 0.5-ha; Johnson 1980, Kaminski and Weller 1992, Kaminski et al. 1993); 3) separation from other blocks by ≥ 200 m to ensure spatial independence (Kaminski et al. 1993); and 4) surrounding landscape that provided vantage point for cryptic observation of dabbling ducks. I delineated plots with white PVC markers and coordinated with TNWR personnel the application of imazapyr (Habitat®, BASF, Research Triangle Park, NC 27709) and Sun Energy surfactant to treatment plots at the rate of 4.677 and 1.169 L/ha, respectively, using a tractor-mounted spray system. Each block included one 0.5−ha plot treated with Habitat® and one 0.5-ha untreated control plot.

I surveyed vegetation diversity, coverage, and structure during June and September 2011–2012 to represent response during the early and late growing seasons. I sampled waterfowl abundances, behaviors, and food resources from 6 January–24 February 2012–2013; the period from initial flooding on experimental blocks through the end of peak waterfowl spring migration in western Tennessee. After plots were flooded (≥60%) in early January, I measured water depths at 10 locations along each of 2 randomly placed transects traversing each block. Using mean water depth from transects, I erected a water depth gauge near each observation blind and recorded mean water depth during each waterfowl observation period (Hagy and Kaminski 2012*b*).

Vegetation Response

I estimated vegetation composition and structure in experimental blocks prior to imazapyr application during June and after treatment in September 2011 to describe early and late growing season vegetation response. I also measured vegetation in June and September 2012 to describe early and late growing season vegetation response one year after treating wetlands with imazapyr. I considered control and treatment plots as the same stand of vegetation prior to treatment and only conducted surveys in treatment plots during this period. I measured percent horizontal cover and mean vegetation height of all plant genera within 10 1-m^2 subplots along a randomly placed transect traversing each plot (Gray et al. 1999, Strader and Stinson 2005). I estimated mean percent cover and height across subplots to obtain a final estimate for each plot (Coulloudon et al. 1999).

Waterfowl Use and Activity

During winters 2012–2013, I estimated waterfowl abundance and recorded bird activities once weekly in experimental blocks at TNWR. I conducted observations of control and treatment plots from concealed, elevated blinds between sunrise and five hours after sunrise. I surveyed plots along predetermined routes and rotated routes weekly among observers to prevent observer bias. Each morning, I surveyed 1–4 blocks, depending on travel distances and logistics of inconspicuous blind entry. Upon entering each blind, I began a five minute waiting period to allow any alerted waterfowl to continue normal behavior. If waterfowl were slightly disturbed by a natural event (e.g., predator), I censored that survey, waited five minutes, and scanned again. If a major disturbance caused departure or redistribution of most waterfowl occupying the wetland, I left the site and returned to survey at another time. I used a rangefinder to estimate distances to

boundary markers and hand-generated diagrams to assist observers in distance estimation during surveys. I did not survey waterfowl during periods of dense fog or high wind (>30 kph).

I identified, enumerated by distance (to nearest 10 m), and described behaviors of dabbling ducks within plot boundaries using 10 × 42 binoculars (Altmann 1974, Davis and Smith 1998, Wirwa 2009, Hagy and Kaminski 2012*b*). I grouped instantaneous behaviors into seven categories: maintenance (i.e., preening and stretching), locomotion (i.e., swimming and walking), foraging, inactive (i.e., at rest and sleeping), courtship, aggression, and alert (Paulus 1984, Morton 1989, Davis and Smith 1998, Eichholz et al. 2009). I did not include birds in flight during surveys (Buckland et al. 2001).

Seed, Tuber, and Invertebrate Biomass

I sampled potential plant (seeds and tubers) and animal (aquatic macroinvertebrate) foods of waterfowl to estimate biomass in control and treatment plots at TNWR. I sampled plots immediately after flooding (late December/early January), and monthly thereafter until late February when waterfowl began spring migration (Stafford et al. 2006, Kross et al. 2008, Hagy and Kaminski 2012*b*). I used a standard core sampler (10 cm depth and diameter) to collect seeds, tubers, and nektonic and benthic macroinvertebrates in shallowly flooded plots (≤45 cm; Murkin et al. 1994, Stafford et al. 2006, Kross et al. 2008, Hagy et al. 2011, Hagy and Kaminski 2012*b*). I used a modified Gerking box sampler to estimate floating seeds, nektonic aquatic invertebrates, and submersed aquatic vegetation in plots that became deeply inundated (>45 cm; Sychra and Adamek 2010).

I collected five core or box samples monthly from all control and treatment plots. I selected a random distance (0–25 m) to the first sample location and then sampled at a

predetermined fixed interval along a transect spanning the plot (Greer et al. 2007, Hagy and Kaminski 2012*b*). Immediately following collection, I rinsed core samples through a 500-µm aperture sieve bucket to remove excess water and soil (Wildco, Buffalo, New York; Wirwa 2009). I deposited the sieved contents in a polyethylene bag, preserved each sample in a 70% ethanol solution, and stored at -10°C until processing (Salonen and Sarvala 1985).

I thawed core samples and stained each with 1% rose bengal solution (≥ 24 hours) to facilitate detection of macroinvertebrates (Manley et al. 2004, Plattner et al. 2010). I removed excess mud and water by washing each through a series of graduated sieves (4.75 mm, 1.40 mm, and 0.3 mm; Kross et al. 2008, Hagy et al. 2011). I removed macroinvertebrates and aquatic vegetation with forceps, enumerated and identified by order and genus respectively, oven-dried for 12–24 hours at 60°C, and weighed to nearest 0.1 mg (Beal 1977, Godfrey and Wooten 1979, 1981, Murkin et al. 1994, Voshell 2002). Next, I added a solution of 3% hydrogen peroxide (H_2O_2) as needed (≤1 min) to remove persistent soils in the remaining sieved contents prior to seed and tuber extraction. When in contact for greater than one minute, hydrogen peroxide may influence invertebrate biomass estimates (H. Hagy, unpublished data). Thus, I waited to use the reagent until after invertebrate removal. I recovered and air-dried sieved contents separately for 24–48 hours or until completely dried.

I extracted seeds and tubers of known or apparent foods of dabbling ducks, because inclusion of non-food items can bias energetic carrying capacity estimates (Straub et al. 2012, Hagy and Kaminski 2012*a*). I recovered seeds and tubers from large and medium sieves (# 4 and #14; hereafter, large portion), and subsampled small sieves (Livolsi et al. 2014). I homogenized materials retained by the small sieve (# 50) and separated a random one-quarter subsample by

mass (hereafter, small portion). I recovered seeds and tubers from small portions of all treatment and control plots in the first month of sampling, and multiplied this estimate by four. Further, I used first month small portion estimates to create a biomass adjustment accounting for seeds ≤1 mm in all other months. I identified seeds and tubers using available literature and a seed collection from previous MAV studies (Fasset 1940, Martin and Barkley 1961, Schummer et al. 2012). I oven-dried seeds and tubers at 60°C for 24 hours and multiplied biomass estimates from large portions by associated small portion adjustment factors to incorporate small seed biomass. I corrected seed abundances using published correction factors to account for recovery and processing bias and report biomass to the nearest 0.1 mg (Hagy et al. 2011).

STATISTICAL ANALYSES

Vegetation Response

Using percent coverage estimates from vegetation surveys, I calculated mean coverage for four distinct categories during each survey period (June and September 2011–2012). I characterized vegetation as desirable, non-desirable, litter, and alligatorweed. I used separate analyses of variance (ANOVA) to test for treatment effects on coverage of desirable vegetation and vegetation height (PROC MIXED; SAS Institute, Cary, NC, Coulloudon et al. 1999, Littell et al. 2006). I designated treatment as a fixed effect, and block nested within year as a random effect. I used logistic regression to interpret the likelihood of alligatorweed presence between treatment and control plots. I selected the model with the lowest Akaike Information Criterion (AIC) score and fewest predictors. I computed goodness-of-fit tests with the Hosmer-Lemeshow test to assess fit of the model (Hosmer and Lemeshow 1989).

Waterfowl Use and Activity

I used multiple covariates distance sampling (MCDS) in Distance 6.0 to account for potential bias associated with distance and emergent vegetation cover (Smith et al. 1995, Buckland et al. 2001, Thomas et al. 2009). Because sample size was small in experimental blocks, I estimated a global detection function and mean detection probability pooled across experimental blocks and moist-soil sites among years from a concurrent study (McClanahan 2015). I used emergent vegetation cover as a covariate with four levels (0–25%, 30–50%, 55–75%, 80–100%), and applied the detection function and detection probability from the global model to estimate weekly waterfowl densities in control and treatment plots. I estimated monthly flooded plot area (ha) using USFWS Lidar imagery, refuge water gauge data, and aerial imagery in ArcMap 10.1® (Environmental Systems Research Institute, Inc., Redlands, CA). I used estimated areas as a sampling fraction to adjust weekly density estimates for irregular plot size and shape (Buckland et al. 2004).

Variation in flooding dates caused beginning dates of observations to differ among years and limited data collection to January and February. I designated the first week post-flood for each block as week one regardless of timing to standardize waterfowl observations among blocks. Densities of dabbling duck species other than mallards were negligible; consequently, I combined densities of all dabbling duck species and used as a dependent variable for density metric (ducks/ha) analyses. I tested effects of imazapyr treatment on dabbling duck densities using repeated measures analysis of variance (ANOVA; PROC MIXED). I designated treatment as a fixed effect, block nested within year as a random effect, and week as the repeated measure.

Further, I measured the association of weekly water depth with weekly dabbling duck density via Spearman rank correlation (McKinney et al. 2006).

I summed counts of instantaneous activities of dabbling ducks across weekly surveys by treatment type and activity. I performed a chi-square test of homogeneity to test for a difference in the percent occurrence of activities in plots treated with imazapyr and control plots in the treatment year and one year post-treatment (PROC FREQ; Zar 2010). I excluded activities courtship, aggression, alert, and maintenance from final analyses due to low occurrence (<10%).

Seed, Tuber, and Invertebrate Biomass

I tested for treatment effects on combined seed, tuber, and invertebrate biomass (kg[dry]/ha) prior to waterfowl use in late November (hereafter, late-autumn) using mixed model ANOVA (PROC MIXED). I performed a similar but separate analysis on food resources from all months thereafter (hereafter, combined winter) to test for an effect after waterfowl began using flooded blocks. For analyses of both late-autumn and combined winter food resources, I designated food biomass as a response variable, treatment as a fixed effect, and block nested within year as a random effect.

Prior to analyses, I examined histograms, variances of response variables, and plots of residuals to ensure assumptions of ANOVA were met (Quinn and Keough 2002, Littell et al. 2006, Zar 2010). I transformed monthly food estimates via square root to equalize variances among effect levels (Quinn and Keough 2002, Zar 2010). When using repeated measures ANOVA, I estimated degrees of freedom via Kenward-Rogers and used Akaike's Information Criterion to select an appropriate covariance structure (Littell et al. 2006). I designated $\alpha = 0.05$

and performed Tukey's pairwise multiple comparison tests of means among treatments when $P < 0.05$. I calculated means and standard errors from untransformed data.

RESULTS

Vegetation Response

Prior to treatment, mean alligatorweed coverage among subplots of treatments was 6.4% (SE = 1.8, $n = 40$) and alligatorweed occurred in 32.5% and 26.3% of vegetation surveys in control and treatment plots, respectively. In 2012, alligatorweed was present in 26.3% of control surveys and 6.3% of treatment surveys. I included year and treatment in the final logistic regression model and found no significant evidence for lack of fit (Wald $X^2 = 19.6$, $P < 0.001$). Alligatorweed was 2.3 times more likely to occur in 2011 than 2012 surveys ($x^2 = 9.2$, $P = 0.003$), and 2.5X more likely to occur in control versus treatments plots (Wald $X^2 = 7.6$, $P = 0.006$). When regressed separately, alligatorweed was 4.2 times more likely to occur in control than treatment plots in 2011 (Wald $X^2 = 5.3$, $P = 0.022$), and 5.3 times more likely in control than treatment plots in 2012 (Wald $X^2 = 10.1$, $P = 0.002$).

I observed differences in percent cover of desirable vegetation ($F_{1, 25.9} = 6.05$, $P = 0.002$, Figure 2.2) and average vegetation height ($F_{1, 30.9} = 2.46$, $P = 0.008$, Figure 2.3) between control and treatment plots. Desirable vegetation cover was 40% greater in control than treatment plot surveys in the year of treatment ($t_{272} = 3.35$, $P = 0.005$), but did not differ between control and treatment plots in 2012 surveys ($t_{272} = 0.91$, $P = 0.801$). Mean vegetation height was 10 cm greater ($t_{275} = 3.35$, $P = 0.005$) in control than treatment plot surveys during the year of treatment, but did not differ between control and treatment plots in post-year surveys ($t_{275} = 0.38$, $P = 0.706$).

Waterfowl Density

Mean detection probability of dabbling ducks in experimental blocks was 52% (SE = 0.3; Figure 2.4). Dabbling duck density did not differ between treatment and control plots ($F_{1, 21.2} = 0.71$, $P = 0.410$). Dabbling duck density was negatively correlated with water depth in treatment ($r^2 = -0.358$, $P = 0.090$, $n = 47$) and control ($r^2 = -0.349$, $P = 0.009$, $n = 46$). Eighty-four percent of dabbling ducks used plots with a mean depth of ≤45cm ($\bar{x} = 26.4$ cm, SE = 0.3, $n = 2449$).

I did not detect a difference in percent occurrence of foraging, resting, or locomotion between control and treatment plots in the year of treatment ($\chi^2 = 3.559$, $P = 0.169$, Figure 2.5) or one year post-treatment ($\chi^2 = 1.317$, $P = 0.599$; Figure 2.5). During winter 2011–2012, I recorded feeding in 65.7% of dabbling ducks surveyed in treatment plots and in 63.6% recorded in control plots. I encountered a lesser proportion of feeding waterfowl during winter 2012–2013 in control (33.5%) and treatment plots (34.2%) than their predecessors in 2011–2012 (65.7% and 63.6%, respectively). Dabbling ducks rested in 15.2% and 18.1% and locomoted in 18.3% and 19.1% of surveys conducted in control and treatment plots, respectively. During 2012–2013, dabbling ducks rested in 35.9% and 35.5% and were locomoting in 30.6% and 30.3% of observations in control and treatment plots, respectively.

I surveyed 38 black ducks ($n = 15$ surveys) in experimental blocks during winters 2011–2013. Generally, I observed more black ducks in control ($n = 24$) than treatment ($n = 14$) plots (63.2% and 36.8%, respectively). I observed feeding in 41.7% and 14.3% of black ducks encountered in control and treatment plots, respectively. I recorded most black ducks ($n = 32$, 84.2%) in experimental blocks during the treatment year of my study.

Seed, Tuber, and Invertebrate Biomass

Combined seed, tuber, and invertebrate biomass from late autumn samples did not differ between plots treated with imazapyr and control plots ($F_{1, 7} = 0.51$, $P = 0.496$, Table 2.1). Combined biomass from late winter samples also did not differ between control and treatment plots ($F_{1, 27.3} = 1.92$, $P = 0.177$). Invertebrates ranged from 0–16.1% of total food biomass in control plots ($\bar{x} = 9.4\%$, SE = 4.6%) and 0.1–19.8% in treatment plots ($\bar{x} = 9.6\%$, SE = 3.3%) across months and years. Seed and tuber biomass combined across plots and years declined 75.6% (SE = 8.4, $n = 16$) in late autumn samples and 23.2% (SE = 11.1, $n = 16$) in combined winter samples. On average, 132.6 kg/ha (SE = 40.7, $n = 8$) and 246.3 kg/ha (SE = 99.7, $n = 8$) of seeds and tubers remained after waterfowl abandoned control and treatment plots, respectively.

DISCUSSION

Personnel at TNWR initiate control of invasive species at relatively low occurrences of alligatorweed (e.g., 10%). Consequently, I did not observe extensive coverage of alligatorweed in plots prior to treatment which may have influenced lack of significant improvement in food density, desirable vegetation cover, and dabbling duck use when compared to un-manipulated plots. Interestingly, imazapyr applications reduced alligatorweed presence in both years, but did not reduce food biomass in the year of treatment. This finding suggests alligatorweed may be controlled with imazapyr with no negative impacts on food resources available to waterfowl in the following winter.

Food biomass did not differ between treated and control plots during the first year of my study likely because of yellow nutsedge *(Cyperus escuelentus*) tuber production in treatment plots, which was twice that of controls. When exposed to chemical stressors, tuber production by

yellow nutsedge is generally negative or relatively unaffected (Costa and Appleby 1976, Stoller and Sweet 1987, Nelson and Renner 2002). However, during the first year of my study, imazapyr appeared to elicit a positive response as biomass of yellow nutsedge tubers were greater in treatment than control plots. Many previous studies report control of yellow nutsedge and associated tubers via pre-emergence or early post-emergence applications of selective herbicides. Imazapyr is a non-selective herbicide and foliar applications of the herbicide late in the growing season kill only aboveground biomass in yellow nutsedge, leaving mature tubers unaffected and dormant until the next growing season (Wilen 1999). Spot-applications of imazapyr late in the growing season have resulted in the release of yellow nutsedge in isolated impoundments at TNWR in recent years (C. Ferrell, personal communication). However, this response is likely due to reduced competition and not increased tuber production (Kelley 1990, Wilen 1999). It is possible that new yellow nutsedge plants emerged and began to produce tubers at the end of the growing season after imazapyr applications killed other species, reducing competition for space and resources. This scenario would explain greater tuber production in treatment plots in the first year, whereas biomass of tubers was similar between control and treatment plots in the second year. Tuber production relies heavily on short photoperiods (Mulligan and Junkins 1976, Stoller and Sweet 1987). Thus, it is plausible that the long growing season in Tennessee permitted emergence of new growth post-imazapyr application, and shortened day length at the end of summer encouraged yellow nutsedge tuberization. Further research is needed investigating yellow nutsedge tuber response to applications of broad-spectrum herbicides late in the growing season in moist-soil wetlands.

Imazapyr effectively reduced vegetation structure and cover of alligatorweed in the year of treatment but effects subsided the following year, consistent with findings in Alabama (Allen et al. 2007). Previous studies have reported a significant increase in desirable wetland plant species in years following treatment with imazapyr and other herbicides (Steenis 1950, Kreuger-Mangold 2002, Allen et al. 2007). Despite having vegetation communities similar to their study area, desirable vegetation cover did not significantly increase in experimental blocks during either year of my study. However, drought conditions during growing seasons of my study may have affected vegetation response (Laubhan et al. 2005, Mitsch and Gosselink 2007, NOAA 2014). Experimental blocks were dewatered by early-mid March and drought conditions during 2011 and 2012 favored more drought-tolerant species (e.g. cocklebur (*Xanthium strumarium*), coffeeweed (*Sesbania herbacea*), and morningglories (*Ipomea spp.*); Fedrickson and Taylor 1982, Strader and Stinson 2005, Schummer et al. 2012). Drought ended in late summer 2012, but was likely too late for moist-soil wetland species to overcome competition from more drought-tolerant plants (Barrat-Segretain 2005).

Similar to food biomass, dabbling duck density did not differ between treatment and control plots in either year of my study. Waterfowl often occur in areas of greatest food biomass (Osborn and Hagy 2014), thus a lack of difference in food resources likely contributed to similarities in dabbling duck densities. Macroinvertebrate biomass in control and treatment plots contributed little to total biomass estimates. I was unable to detect consistent invertebrate biomass in samples relative to seeds and tubers (< 5%), likely because invertebrate production was simultaneously influenced by numerous ecological and environmental factors (e.g., detritus, hydrology, water chemistry, and predation; Batzer 2013). Food estimates of treatment plots

averaged across years were similar (605.7 kg/ha) to estimates of moist-soil wetlands reported in other studies (496.3 kg/ha, Kross et al. 2008; 691.3 kg/ha, Stafford et al. 2011). Additionally, food biomass in treatment and control plots were similar to those in other moist-soil wetlands at TNWR during a concurrent study (683.4 kg/ha, Chapter II). To my knowledge, no previous investigations of belowground food biomass exist in wetlands experimentally treated with herbicides.

Mean vegetation height in my study was >10 cm higher in control than treatment plots in the treatment year and both had tall, dense post-year vegetation. Waterfowl may avoid use of wetlands when vegetation is robust (Hagy and Kaminski 2012*b*), but openings created via mechanical methods or "spot-treatment," result in hemi-marsh conditions and influence waterfowl use (Kaminski and Prince 1981; Linz et al. 1996, 1997; Smith et al. 2004; Moon and Haukos 2008). Imazapyr treatments during my study were applied in late summer and thorough (i.e., not "spot-treatments"). Once flooded, dead vegetation toppled and treatment plots resembled open water during the treatment year. Experimental blocks (instead of treatment plots alone) then, loosely mimicked "hemi-marsh" conditions, with treatment plots serving as the open water component juxtaposed to the vegetated control plots. Waterfowl appeared to use this boundary joining control and treatment plots which likely contributed to similar dabbling duck use in treatment-year plots. Further, vegetation height in the post-treatment year was similar between control and treatment plots and likely resulted in similar dabbling duck use.

Consistent with other research in the southeastern United States (Hagy and Kaminski 2012*b*), dabbling duck density decreased in both control and treatment plots when water depth increased. During my study, 84% of dabbling ducks used plots with ≤45 cm water depth, and

ducks likely abandoned plots when water depths prevented efficient foraging of submersed or benthic foods. Activities did not differ between control and treatment plots, indicating that functional use of moist-soil wetlands by waterfowl did not change after herbicide was applied. Although a greater percentage of dabbling ducks were recorded feeding in 2011 than 2012, waterfowl activities were not significantly different between control and treatment plots each year. I speculate that this similarity resulted from temporal differences of flooding between years, as well as similar vegetation structure (post-treatment year) and food biomass (pre-treatment and post-treatment years).

Interestingly, black ducks commonly occur in distinct locations at TNWR, often returning to the same locations in subsequent years (R. Wheat, USFWS, personal communication). Although reasons for this phenomenon are unknown, food density is likely not a driving factor (Chapter II). A large proportion of black ducks observed during my study occurred in one block over multiple surveys. The block, located in Pool One of TNWR, is located in an area of consistently high black duck use. Considering low foraging effort and use by black ducks in previous years, perhaps black duck use in this area may have been coincidental rather than opportunistic. Low food biomass may have also contributed to low use and foraging effort overall. However, recent models suggest that food density, while important, may only account for a small portion of variation in duck distribution. Black ducks did not apparently respond to imazapyr-treatment and subsequent vegetation community changes in moist-soil wetlands during my study. Had plots contained higher proportions of alligatorweed, vegetation response may have been more influential on black duck and other dabbling duck use. Further, in

the absence of treatment, coverage of alligatorweed would have increased and perhaps further degraded black duck and other dabbling duck habitat.

Future studies involving imazapyr treatment in wetlands should incorporate areas with greater coverage of alligatorweed. Studies should be conducted in areas where yellow nutsedge, or other tuber-producing plants can be monitored and experimentally challenged. Future work should examine more than one post-treatment year and incorporate vegetation interspersion metrics during vegetation surveys and in equal intervals post-flooding. Nocturnal habitat use by waterfowl should also be investigated and compared with diurnal surveys from the same wetlands to elucidate functional differences during different periods of the day.

MANAGEMENT IMPLICATIONS

Results from my study suggest imazapyr is a valuable tool to control alligatorweed in moist-soil wetlands, but results in a loss of desirable vegetation cover in the treatment year. However, in the absence of competition from imazapyr-treated vegetation, new plant communities may establish and produce high-energy tubers for waterfowl. Further, effects of imazapyr-treatment in moist-soil wetlands wetlands on dabbling ducks were not evident during my study. Thus, managers should treat moist-soil wetlands with imazapyr in late summer to control alligatorweed. Differing vegetation communities among regions and greater coverage of alligatorweed could result in differing waterfowl responses post-treatment. Managers controlling alligatorweed with imazapyr should provide an alternate source of vegetation cover for wintering dabbling ducks where possible, as emergent cover may be diminished in the treatment year. In wintering areas where alternate means of emergent vegetation cover are limited, managers should consider “spot-treatment” in seasonally flooded, impounded wetlands. Control of alligatorweed and improved

quality of managed wetlands using imazapyr requires further investigation, particularly regarding treatment of greater coverages of alligatorweed as well as tuber production post-treatment.

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APPENDIX B: TABLES AND FIGURES

Table 2.1. Biomass estimates (kg[dry]/ha) of foods apparently consumed by waterfowl in 0.5-ha plots treated with imazapyr and adjacent un-manipulated plots (control) during winters 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge, Tennessee, USA.

			November		December[a]		January		February	
Year	Food Type	Treatment	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
2011	Seeds	Control	253.4	109.2	64.2	41.3	71.7	30.1	47.2	31.2
		Herbicide	98.2	42.1	108.0	64.9	49.2	36.3	102.3	69.8
	Tubers	Control	185.6	85.3	162.4	68.5	152.9	54.8	105.4	56.5
		Herbicide	467.3	208.1	290.9	90.3	261.9	153.5	152.3	69.0
	Invertebrates	Control	4.0	1.0	12.6	5.6	23.6	13.0	13.6	9.1
		Herbicide	0.6	0.4	4.7	2.0	12.3	3.6	1.6	0.4
	Total	Control	443.0	163.8	239.3	99.6	248.2	85.1	166.1	82.1
		Herbicide	566.1	244.4	329.6	119.9	223.4	112.0	245.8	99.3
2012	Seeds	Control			666.4	-	179.2	65.0	61.8	53.0
		Herbicide			286.1	-	509.5	325.1	30.2	18.8
	Tubers	Control			277.8	-	68.5	44.7	28.2	25.7
		Herbicide			201.6	-	100.6	52.3	88.8	40.9
	Invertebrates	Control			8.4	-	5.9	2.8	9.1	2.5
		Herbicide			15.8	-	3.6	0.9	7.8	4.0
	Total	Control			952.8	-	292.8	100.7	99.1	49.6
		Herbicide			503.6	-	613.7	301.5	128.9	103.0

[a] Only one experimental block flooded during December 2012

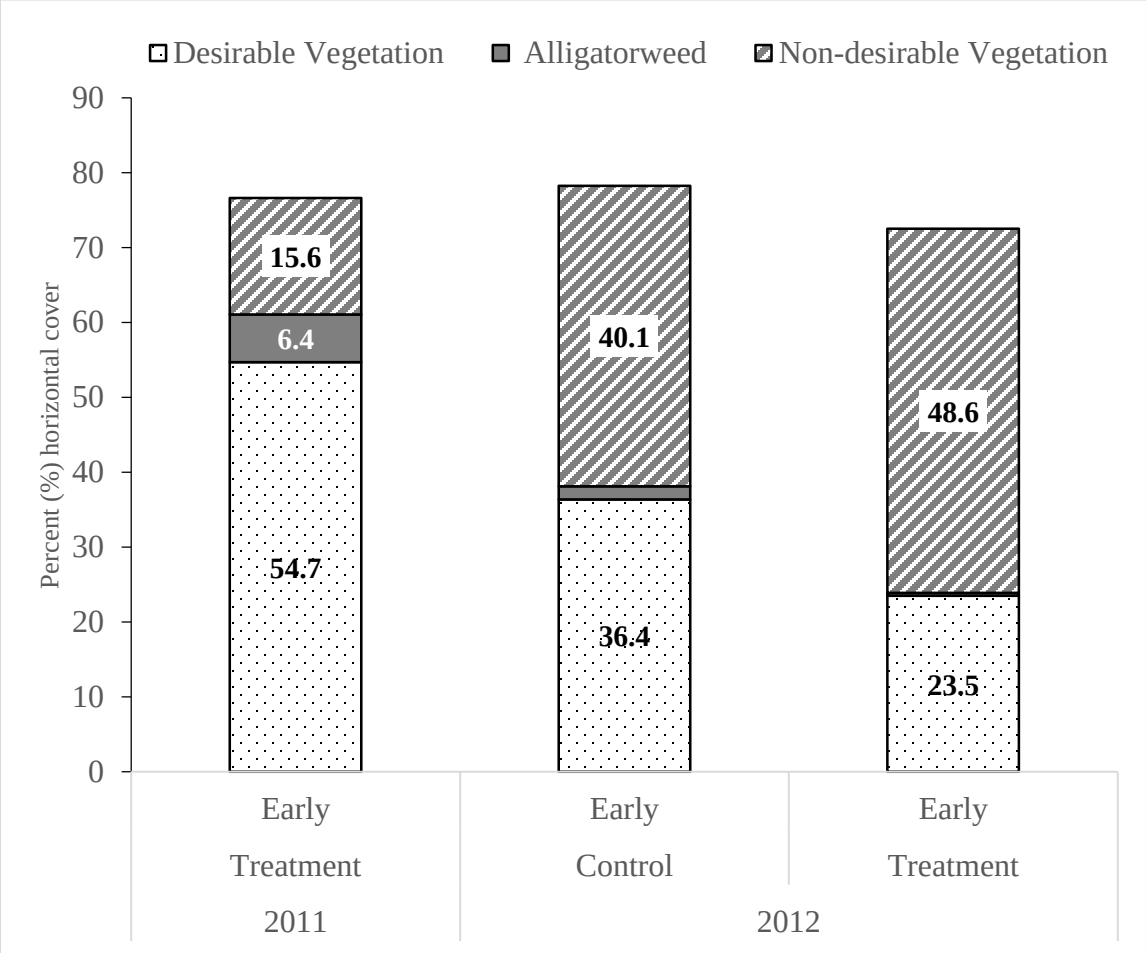

Figure 2.1. Pre-treatment (July 2011) and early growing-season (July 2012) estimates of percent horizontal cover of vegetation typically consumed by waterfowl (desirable vegetation), alligatorweed (*Alternanthera philoxeroides*), and vegetation not consumed by waterfowl (non-desirable vegetation) in 0.5-ha plots treated with imazapyr and adjacent un-manipulated plots (control), during treatment (2011) and post-treatment (2012) years at the Duck River Unit of Tennessee National Wildlife Refuge, Tennessee, USA.

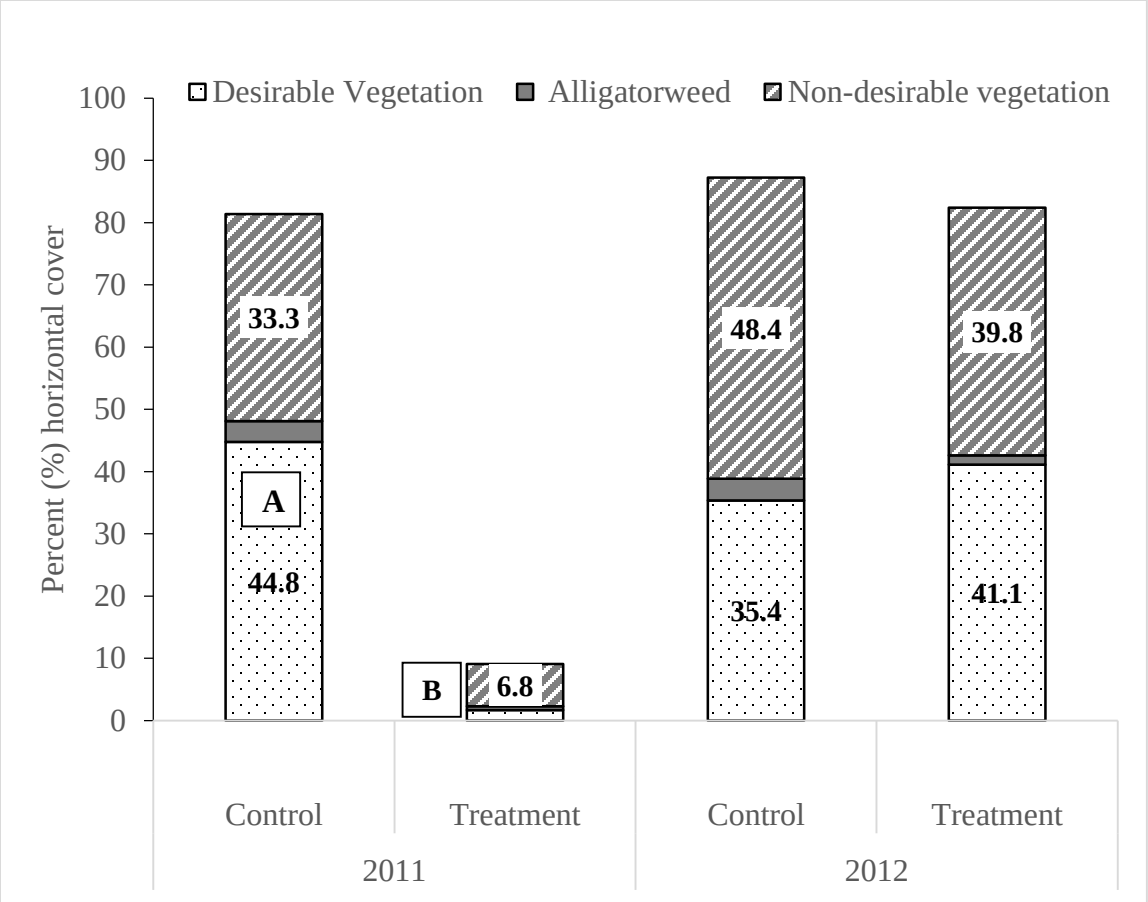

Figure 2.2. Post-treatment estimates (September) and comparisons[a] of percent horizontal cover of vegetation typically consumed by waterfowl (desirable vegetation), alligatorweed (*Alternanthera philoxeroides*), and vegetation not consumed by waterfowl (non-desirable vegetation) in 0.5-ha plots treated with imazapyr and adjacent un-manipulated plots (control), during treatment (2011) and post-treatment (2012) years at the Duck River Unit of Tennessee National Wildlife Refuge, Tennessee, USA.

[a] Columns with different capital letters are significantly different ($P < 0.05$) based on Tukey-Kramer *post hoc* comparisons of least squares means. Comparisons made among foods only.

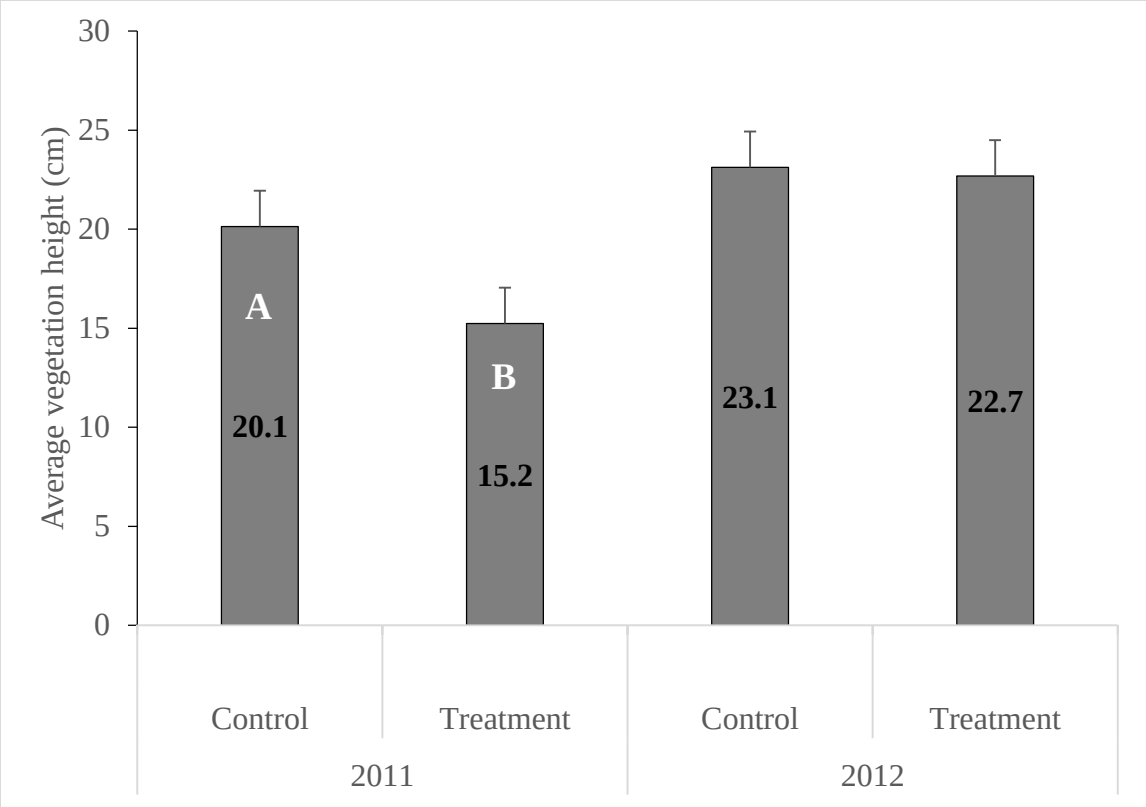

Figure 2.3. Post-treatment estimates and comparisons[a] of average vegetation height (cm) estimated in 0.5-ha plots treated with imazapyr and adjacent un-manipulated plots (control) in September of treatment (2011) and post-treatment (2012) years at the Duck River Unit of Tennessee National Wildlife Refuge, Tennessee, USA.

[a] Columns with different capital letters are significantly different ($P < 0.05$) based on Tukey-Kramer *post hoc* comparisons of least squares means.

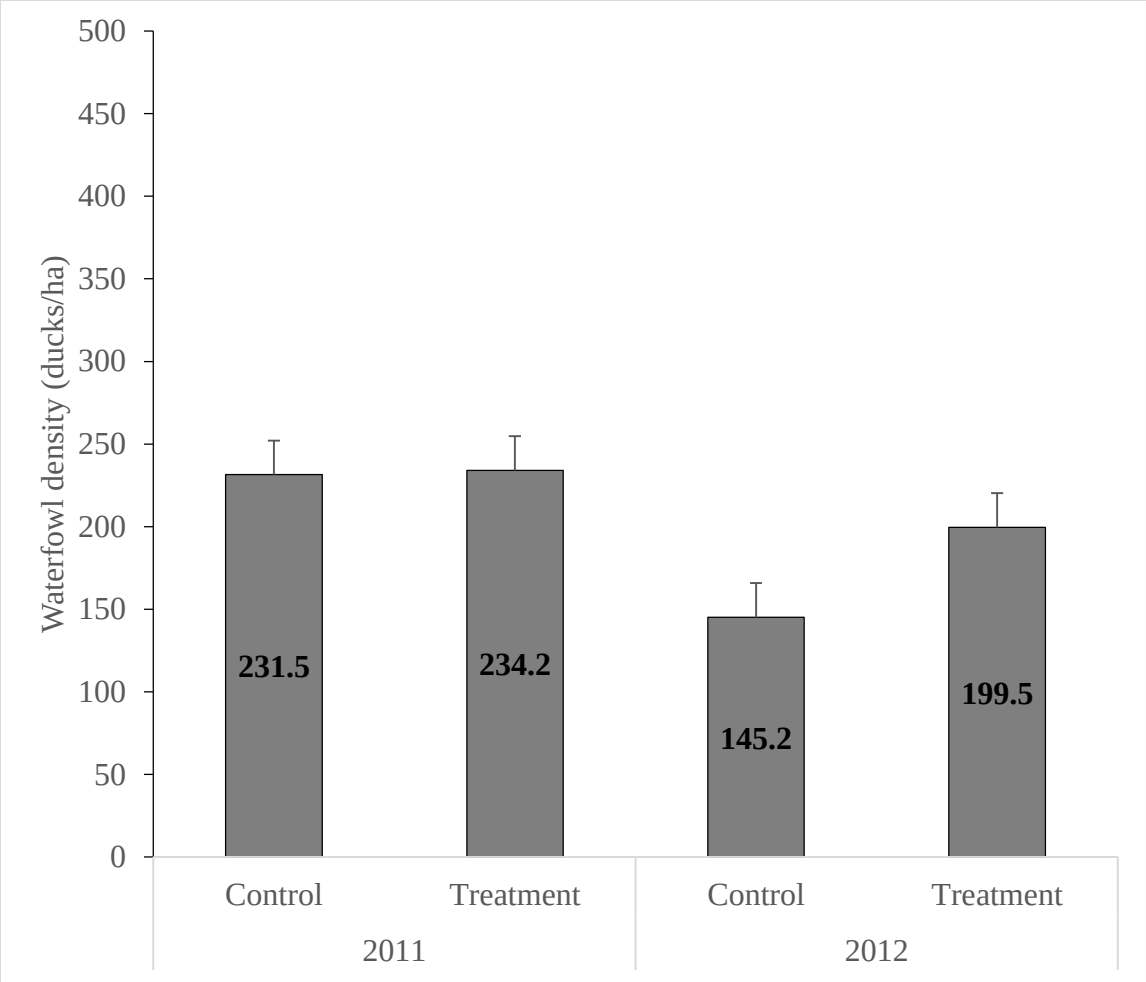

Figure 2.4. Density of dabbling averaged across the first seven weeks of surveys post-flooding in 0.5-ha plots treated with imazapyr and adjacent un-manipulated plots (control) during winters 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge, Tennessee, USA.

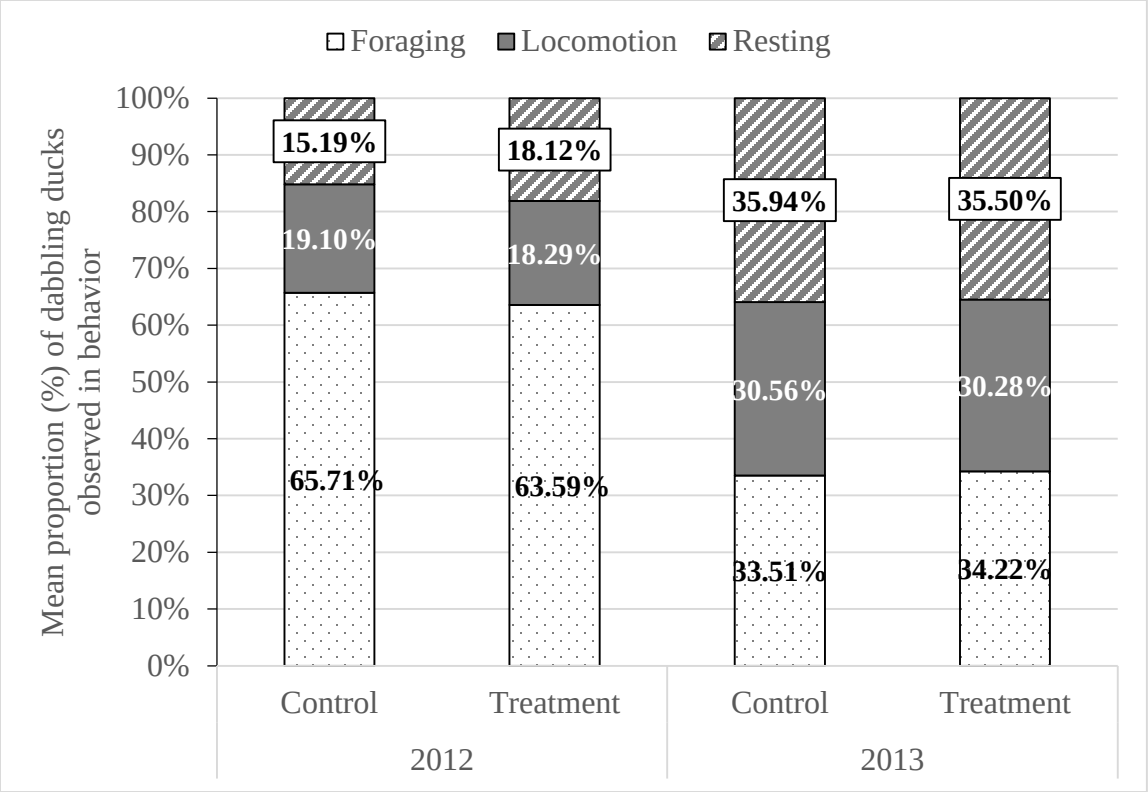

Figure 2.5. Mean proportion of dabbling ducks engaged in foraging, locomotion, and resting during scan-sampling observations in 0.5-ha plots treated with imazapyr and adjacent, un-manipulated plots (control) during winters 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge, Tennessee, USA.

CHAPTER IV: EXECUTIVE SUMMARY

American black ducks (*Anas rubripes*, hereafter black ducks) in the Mississippi Flyway have suffered significant and continuous declines since the beginning of the U.S. Fish and Wildlife (USFWS) Mid-winter Waterfowl Survey (MWS) in 1955 (USFWS 2014*b*). Several factors, including habitat loss and degradation, have been implicated in the decline and often debated by researchers (Rusch et al. 1989, Conroy et al. 1989). Habitat loss is particularly detrimental during winter, a time when energy demands for waterfowl are at their greatest (Baldassare et al. 1986). Western Tennessee is an important wintering area for Mississippi Flyway black ducks, but habitat loss in the region due to river channelization and urban and agricultural expansion has been severe (Reid et al. 1989, Dahl 2011, USFWS 2014*a*). Consequently, knowledge of habitat use patterns becomes especially important in order to manage a dwindling population using dwindling resources. Information is needed that identifies important habitat characteristics and informs management of black ducks based on life-history needs (Turnbull and Baldassare 1987). Improving moist-soil wetlands, which serve as foraging areas for black ducks, often requires herbicide-treatment to control invasive or persistent undesirable plants (Madsen et al. 1997, Strader and Stinson, 2005, Allen et al. 2007). Formal testing of management using herbicide is necessary to determine responses of emergent vegetation, waterfowl use, and food availability. Answering these research questions will benefit habitat conservation on a changing landscape, and contribute to restoration of energetically-important areas for black ducks and other waterfowl (Devers and Collins 2011, NAWMP 2012).

During winters 2011–2013 (December–February), I estimated diurnal habitat use, activities, and food availability for black ducks among six cover types common throughout the Duck River Unit of Tennessee National Wildlife Refuge (TNWR) and Cross Creeks National

Wildlife Refuge (CCNWR), two waterfowl sanctuaries in western Tennessee (Chapter II). I sampled fixed-sites weekly (n = 4 for each cover type at each refuge) and mobile plots monthly (sites of recent black duck use) to infer patch selection. I compare results from my study with those of concurrent studies of black ducks (Newcomb 2014) and dabbling duck communities (McClanahan 2015). In Chapter III, I executed a separate study at TNWR examining vegetation community responses, winter food densities, and use and activities of non-breeding dabbling ducks in four 1-ha experimental blocks of moist-soil vegetation. Each block contained one 0.5-ha plots treated with imazapyr (hereafter, treated plot), and one 0.5-ha plot which was not treated (hereafter, control plot). I coordinated with TNWR personnel the application of imazapyr in July 2011, and measured responses for treatment year and one year post-treatment. In July and September of 2011 and 2012, I measured percent horizontal cover of vegetation beneficial to waterfowl (foods), average vegetation height (cm), and noted presence of alligatorweed (*Alternanthera philoxeroides*) among subplots within each block. I evaluated winter dabbling duck and food availability concurrently with work from Chapter II. I provide a brief summary and management implications from each study below.

Habitat use of black ducks was greatest in scrub-shrub wetland (Table 1.4, Chapter II, see Appendix B for tables and figures), supporting results from a concurrent study (Newcomb 2014). Likelihood of black duck use was also high in flood corn, although use in these areas was short-lived and variable over time. Black ducks also used sites containing submersed aquatic vegetation (SAV), as well as moist-soil wetlands (Table 1.4). Foraging, locomoting, and resting dominated black duck activities in all cover types (approximately 90% combined). Foraging was greatest in moist-soil wetlands, flooded corn, and mudflats, and lowest

in open water areas, where little to no foraging occurred (Table1.8). Black ducks spent more time at rest in open water (33.2%) than other cover types (Table 1.8). Black duck habitat use overlapped with mallards in scrub-shrub, moist-soil, flooded corn, and mudflats (McClanahan 2015).

Biomass (kg[dry]/ha) of seeds, tubers, and SAV in sites of recent black duck use was greatest in moist-soil wetlands ($\bar{x}$ = 303.7 kg/ha). Invertebrate biomass in sites selected by black ducks were greatest in scrub-shrub wetlands ($\bar{x}$ = 26.7 kg/ha), moist soil ($\bar{x}$ = 24.9 kg/ha), and mudflats ($\bar{x}$ = 20.2 kg/ha). Black ducks selected areas with similar food biomass (seeds, tubers SAV, and invertebrates) throughout winter (Table 1.6), but consistently selected sites with lower available food resources than available in fixed-sites from a concurrent study (McClanahan 2015). Open water was the most available area among those studied at TNWR and CCNWR (Table 1.2), followed by moist-soil wetlands and flooded scrub-shrub.

In Chapter III (see Appendix B for tables and figures), percent cover of desirable vegetation was greater in control than treatment plots in the year of treatment, but did not differ in the post-treatment year (Figure 2.2). Likewise, average vegetation height was greater in control than treatment plots in the year of treatment, but did not differ in the post-treatment year. Dabbling duck densities (ducks/ha) and total food biomass (seeds, tubers, and invertebrates, kg[dry]/ha) did not differ among control and treatment plots during either year of my study. I did not observe significant use of experimental blocks by black ducks. Dabbling duck density was negatively correlated with increasing water depth ($r_s = 0.36$, $P < 0.10$) in control and treatment plots pooled across years.

Results from Chapter II support Newcomb (2014), and suggest that scrub-shrub wetlands are consistently important for non-breeding black ducks in western Tennessee. Additionally, moist-soil wetlands serve as foraging areas and may be necessary to meet energetic needs of black ducks throughout winter. Flooded corn, while providing foraging substrate to black ducks in Tennessee, potentially serves as a platform for increased interactions and potential hybridization with mallards. Where possible, acreage of flooded corn on refuges important to black ducks should be limited and logistically placed in areas furthest from sites of repeated or historic black duck use. Managers should also incorporate moist-soil management amidst scrub-shrub wetlands to meet needs of non-breeding black ducks in the short term. Scrub-shrub wetlands are uncommon, but important to black ducks and myriad other waterfowl species (McClanahan 2015). Thus, restoration of scrub-shrub wetlands throughout areas important to black ducks may be necessary to maintain or restore populations to BDJV goals. Future research should examine the efficacy of including benefits other than food densities into habitat quality models.

Results from Chapter III suggest that imazapyr is a valuable tool for controlling alligatorweed in moist-soil wetlands. Overall percent cover of alligatorweed was minimal prior to treatment, and may have contributed to a lack of response in desirable vegetation communities and waterfowl use. However, alligatorweed presence was reduced, without negatively impacting available food resources in treatment or post-treatment years. Treatment-year plots contained disproportionately greater tuber biomass than post-treatment year plots, which also likely contributed to the lack of significant differences in seed densities among control and treatment plots in the pre-treatment year. Further research into this phenomena is warranted, as tubers are

high in energetic value and often selected by waterfowl (Table 3.1; Mendall et al. 1949, Gyimesi et al. 2011). Additionally, similar studies should be conducted on imazapyr treatment in wetlands with greater coverage of invasive plants to more effectively test response of plant communities. Managers should continue traditional active management in moist-soil wetlands that do not contain invasive plants, and complement management with shallow flooding in winter to provide maximum benefits to non-breeding waterfowl.

Black ducks did not appear to benefit from imazapyr-treatment of moist-soil wetlands during my study (Chapter III), nor did they benefit from disking and subsequent planting of millet (McClanahan 2015). My results suggest food densities do not drive habitat-selection in western Tennessee. Instead, black ducks select scrub-shrub wetlands and, when necessary, move to among other cover types, specifically moist-soil wetlands and flooded corn, to forage. Future work is needed to identify more specific characteristics that may enhance suitability of wetland complexes for non-breeding black ducks. Such research will inform habitat management for black ducks and aid in restoring populations to Black Duck Joint Venture Goals.

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APPENDIX C: TABLES AND FIGURES

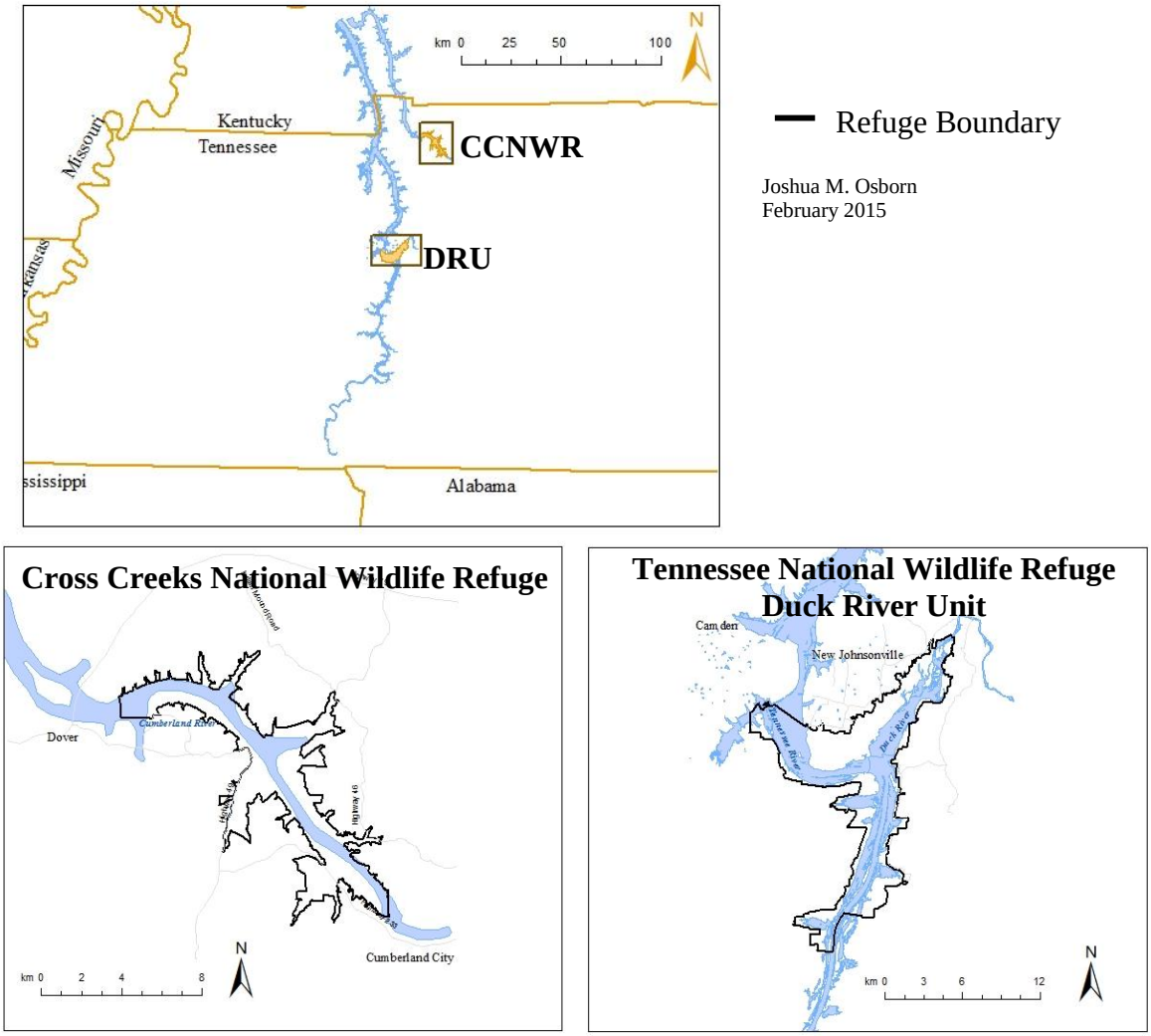

Figure 3.1. Geographic locations of the Duck River Unit of Tennessee National Wildlife Refuge (TNWR) and Cross Creeks National Wildlife Refuge (CCNWR) within the Tennessee and Cumberland River watersheds.

Figure 3.2. Modified Gerking box sampler (a–b) and 10 cm core sampler (c) used to collect food resources during November–February 2011–2013 at the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge, Tennessee, USA.

Table 3.1. Seeds, tubers, and submersed aquatic vegetation (SAV) apparently consumed by waterfowl and aquatic macroinvertebrates from core samples and modified Gerking box samples, their true metabolizable energy values (TME; kcal/g), and references recovered during November–February 2011–2013 from the Duck River Unit of Tennessee National Wildlife Refuge and Cross Creeks National Wildlife Refuge.

Food Type and Taxa		TME	Source[a]
Seeds, Tubers, and SAV			
Amaranthaceae			
	Amaranthus spp.	2.97	Checkett et al. 2002
Asteraceae			
	Bidens spp.	0.55	Sherfy 1999
Boraginaceae			
	Heliotropium indicum	2.39	Kaminski et al. 2003, Hagy 2010
Ceratophyllaceae			
	Ceratophyllum demersum (foliage)	1.24	Brasher et al. 2007 and Straub 2008
Cyperaceae			
	Carex spp.	1.36	Straub 2008
	Cyperus esculentus (tubers)	4.03	Petrie et al. 1998
	Cyperus spp. (seeds)	1.69	Sherfy 1999, Ballard et al. 2004
	Elocharis spp.	0.16	Sherfy 1999, Dugger et al. 2007
	Rhynchospora spp.	1.86	Checket et al. 2002
	Scirpus spp.	0.93	Sherfy 1999, Ballard et al. 2004, Dugger et al. 2007
Fabaceae			
	Glycine max	2.65	Reinecke et al. 1989
Fagaceae			
	Quercus spp.	2.75	Kaminski et al. 2003
Haloragaceae			
	Myriophyllum spicatum (foliage)	0.61	Straub 2008
Juncaceae			
	Juncus spp.	1.21	Sherfy 1999
Lemnaceae	*Lemna* spp.	0.90[b]	Muztar et al. 1978

Table 3.1. Continued.

Food Type and Taxa		TME	Source[a]
Seeds, Tubers, and SAV			
Malvaceae			
	Hibiscus spp.	2.39	Kaminski et al. 2003
	Sida spinosa	2.19	Straub 2008
Onagraceae			
	Ludwigia spp.[c] (foliage)	1.77	Straub 2008
Poaceae			
	Dicanthelium spp.	2.45	Sherfy 1999, Checket et al. 2002
	Digitaria spp.	3.10	Checkett et al. 2002
	Echinochloa spp.	2.62	Reinecke et al. 1989, Sherfy 1999, Sherfy et al. 2001, Checkett et al. 2002
	Eragrostis hypnoides	2.39	Kaminski et al. 2003
	Leersia oryzoides	2.91	Hoffman and Bookhout 1985
	Leptochloa spp.	2.64	Yerkes et al. 2009
	Panicum spp.	2.45	Sherfy 1999, Checket et al. 2002
	Paspalum spp.	1.57	Checkett et al. 2002
	Setaria spp.	2.88	Checkett et al. 2002
	Sorghum halepense	2.73	Straub 2008
	Urochloa platyphylla	2.73	Straub 2008
	Zea mays	3.67	Reinecke et al. 1989
	Zizaniopsis miliacea	2.91	Mean of *Leersia oryzoides* (Hoffman and Bookhout 1985)
Polygonaceae			
	Polygonum spp.	1.21	Hoffman and Bookhout 1985, Sherfy et al. 2001, Checkett et al. 2002, Ballard et al. 2004
	Rumex crispus	2.68	Checkett et al. 2002
Potamogetonaceae			
	Potamogeton spp. (seeds)	0.61	(Straub 2008)
Rubiaceae			
	Cephalanthus occidentalis	0.78	Straub 2008
	Diodia virginiana	2.39	Kaminski et al. 2003

Table 3.1. Continued.

Food Type and Taxa		TME	Source
Invertebrates			
Annelida			
	Clitella	0.58	Mean of published TME for invertebrates (Straub 2008)
	Oligochaeta	0.64	Yerkes et al. 2009
Arachnida		0.58	Mean of published TME for invertebrates (Straub 2008)
Bivalvia		0.22	Jorde and Owen 1988, Ballard et al. 2004
Gastropoda		0.29	Sugden 1971, Sherfy 1999
Insecta			
	Coleoptera	0.38	Mean TME for Insecta (Sherfy 1999)
	Diptera	0.27	Sherfy 1999
	Ephemeroptera	0.38	Mean TME for Insecta (Sherfy 1999)
	Hemiptera	0.48	Sherfy 1999
	Odonata	0.38	Mean TME for Insecta (Sherfy 1999)
	Plecoptera	0.38	Mean TME for Insecta (Sherfy 1999)
	Trichoptera	0.38	Mean TME for Insecta (Sherfy 1999)
Malacostraca			
	Amphipoda	2.33	Sugden 1971, Ballard et al. 2004
	Decapoda	0.91	Mean TME for Malacostraca (Straub 2008)
	Isopoda	0.08	Sherfy 1999

[a] TME value is mean of values listed among sources

[b] Gross energy values (GE) converted to TME assuming 22.3% digestibility of various SAV reported by Hoffman *et al.* 1983. (Brasher *et al.* 2007).

[c] Strongly aquatic *Ludwigia* species (i.e., *L. palustris*, *L. peploides*, and *L. repens.*)

VITA

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